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ABSTRACT

Rear projection systems and their requirements and limitations are discussed in the light of projection equipment, screens, the observer, and physical surroundings. Performance criteria for rear projection systems for use in the communication-lecture hall centers are revealed, based on an evaluation of nineteen different systems. Design recommendations and standards for the viewing of projected images, and selection of projection components are given. Various seating and equipment layout plans are included, along with environmental criteria, and a glossary, graphs, and drawings. (TG)

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COMPONENTS FOR REAR PROJECTION SYSTEMS

establishing criteria for rear projection systems
for use in the communication-lecture hall centers,
state university of new york.........october 1964.

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* William F. Winslow , associate investigator

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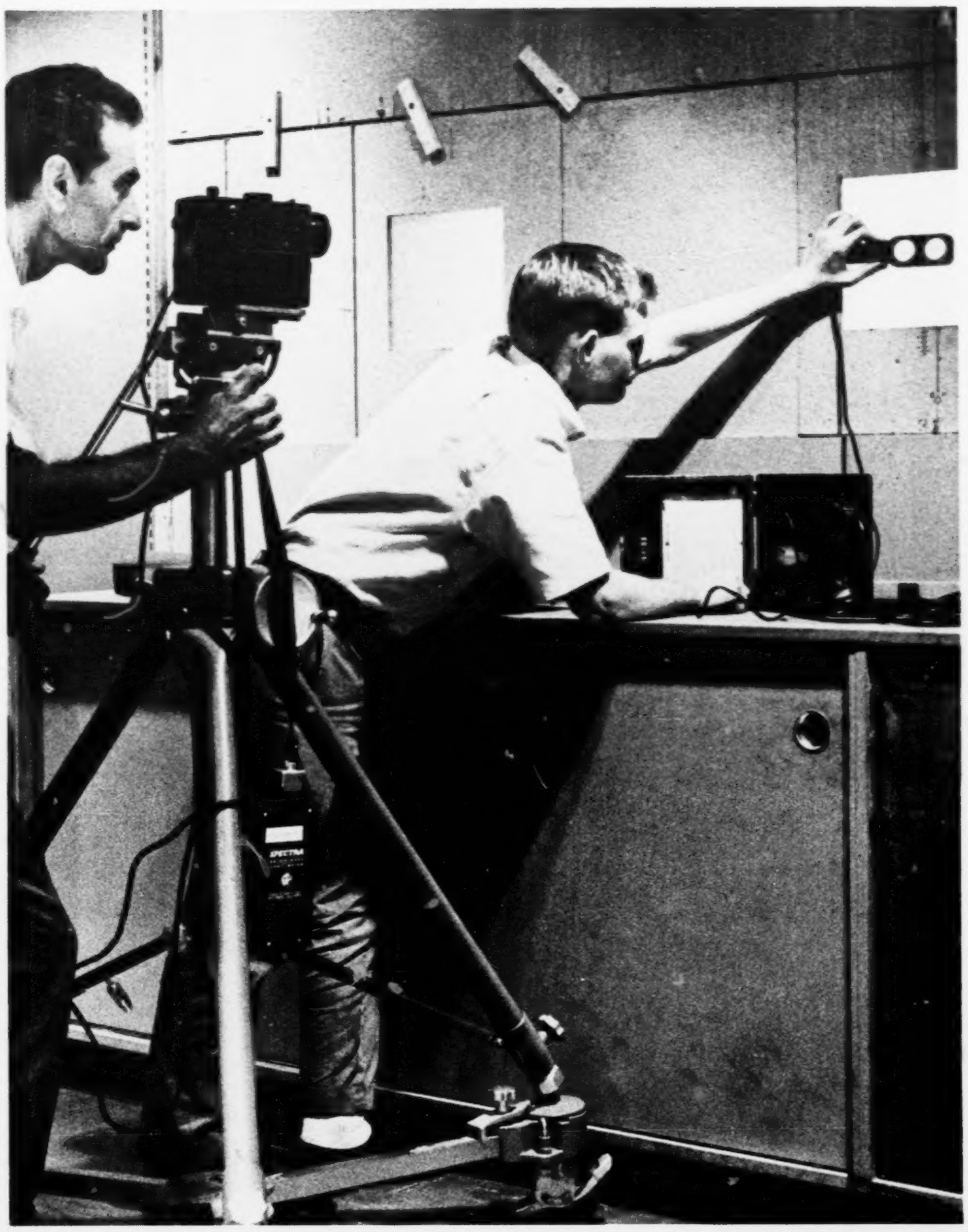
This is a report of a study undertaken by the Research Staff of the School of Architecture, Rensselaer Polytechnic Institute, Troy, New York for the Office of Facilities, State University of New York, Albany, New York...



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FOREWORD

In 1963 the School of Architecture at Rensselaer Polytechnic Institute, under contract to the State University of New York, completed studies for the design of seating, lighting, and acoustics[1] as required by SUNY's newly proposed communication and lecture hall centers. As a logical extension of this work, the same Sponsor requested that investigations be made concerning the selection of rear projection equipment and lighting in these spaces[2].

Specifically, it was requested that this investigation deal with

- the selection of appropriate projection equipment
- the choice of appropriate screens
- recommended permissable lighting levels at the screen surfaces
- recommended lighting levels at the task surfaces in the room

Work was begun in June of 1964 and completed in early October; this is the report of the project.

For many years the Society of Motion Picture and Television Engineers, various research groups, individuals and manufacturers have conducted thorough studies in relation to projection systems for motion pictures and slides. The purpose of these studies has been to establish standards for the industry for both equipment and viewing. Until fairly recently, most of this work has been in the area of front projection systems.

The increasing use of Visual Aids in the classroom (and the related special problems of room darkening and equipment use) has stimulated interest in the use of rear projection systems. While many of the standards developed for professional front screen projection are applicable to rear screen projection in classrooms, certain special problems have arisen. Among these problems are the use of greater width to depth ratios for seating; the need for higher lighting levels in the room during projection, and the use of remote controlled and reasonably economical projection equipment.

The purpose of this study has been to determine the limitations of these problems and establish classroom standards and procedures for the selection and use of rear projection equipment.

A successful rear projection system must recognize the requirements and limitations of the projector, the screen, the observer and the enclosure. Careful co-ordination and adjustment of all components is essential to the production of a satisfactory projected image.

Peter Vlahos[2] has tabulated nine interrelated factors which must be carefully co-ordinated to produce such an image. The relationship of the nine factors listed will be demonstrated in following sections:

1. Screen Gain
2. Screen Reflection Factor
3. Screen Brightness
4. Maximum Bend Angle
5. Contrast
6. Ambient Light
7. Projection Lens Focal Length
8. Picture Size
9. Projector Lumen Output

Each of these terms, as well as others pertinent to this project, are defined in Section II - Definition of Terms.

SECTION 11 - DEFINITION OF TERMS

The following definitions are limited, where necessary for clarity, to their specific application to rear projection systems.

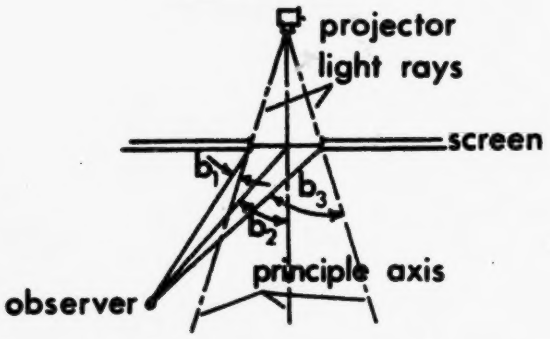
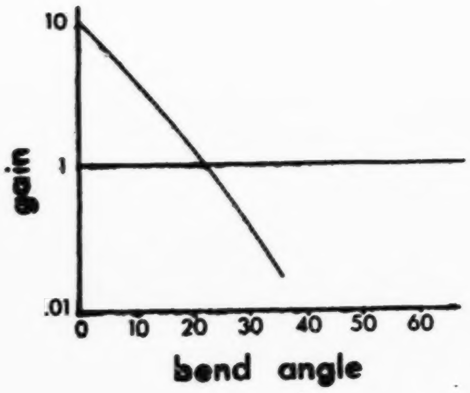
FOOT CANDLE: unit: (ft C)	Unit of measure of the intensity of light incident on a surface.
FOOT LAMBERT: unit: (ft L)	Unit of measure of the intensity of light reflected or emitted from a surface.
AMBIENT LIGHT: unit: (ft C) incident (ft L) reflected	Any stray, non-image producing light which strikes the front or back of a rear projection screen. (In this study, ambient light is measured with the projector on, the lens capped, and room lighting on).
BEND ANGLE:  projector light rays screen b_1 b_3 b_2 principle axis observer	An angle described by the position of an observer and any given light ray produced by the projector. (B_1 B_2 B_3 etc.) MAXIMUM BEND ANGLE: The largest angle described by a fixed position of the observer and the outermost ray produced by the projector. (B_3)
BRIGHTNESS: unit: (ft L)	Response of the human eye to transmitted or reflected light. Brightness is the luminous intensity of any surface in a given direction. Brightness is independent of viewing distance.
BRIGHTNESS LEVEL: unit: (ft L)	Measure of the luminous intensity (or brightness) of a given surface.
BRIGHTNESS RATIO: unit: $\frac{(ft\ L)}{(ft\ L)}$	The ratio between the maximum and minimum brightnesses on a screen as seen from any given observing position.

IMAGE BRIGHTNESS: unit: (ft L)	Screen brightness measured with the projector running, but no film in the projector.
NON-IMAGE BRIGHTNESS:	Screen brightness measured with the projector running with the lens capped and room lighting on. Non-image brightness, due to room lighting only, is the product of the room ambient light falling on the screen (ft C) x the Screen Reflection Factor.
OPEN APERTURE BRIGHTNESS:	The brightness at which projected images are viewed is defined by the American Standards Association as that screen brightness obtained with the projector operating without film in the projector aperture, or open aperture. All brightnesses referred to in this monograph are open aperture.
CONTRAST RATIO:	Ratio of: $\frac{\text{image brightness}}{\text{non-image brightness}}$ for any given observing position.
GAIN:	A screen characteristic which (in its simplest terms) measures the "input" of light from the projector into the screen and compares this with the output from the screen. Gain, therefore, is the ratio of observed brightness in foot lamberts to incident illumination in foot candles. $\text{gain} = \frac{\text{foot lamberts}}{\text{foot candles}}$ An ideal reference screen would transmit 100% of the incident light and diffuse it perfectly to provide the same brightness at all viewing angles for a gain figure of 1.

GAIN CURVE:  	A logarithmic graph showing the gain characteristics of a screen. The ordinate represents screen gain based on an ideal reference screen at 1. The abscissa represents gain values at various bend angles from any principal axis. If a small area of any screen is observed, it is found that the brightness decreases as the observer moves from a viewing position (along a principal axis) through increasing bend angles. Since the "input" for the area is constant, the decrease in brightness is due to decreasing gain values.
LUMEN:	Unit of light measurement which measures luminous flux. A uniform point source equal to one candle is shown at the center of a sphere of 1 foot Radius. The illumination at any point on the sphere is equal to one foot candle (1 lumen per square foot).
PROJECTOR LUMEN OUTPUT:	A projector characteristic comparable to the "horse power" rating of a motor. Projector output (lm) = average incident illumination (ft C) x picture size (sq.ft.). In this report, the three point system of measuring illumination has been used. An average of three readings taken in foot candles at the center of the screen and two side readings taken at 5% from the edges is sufficiently accurate for screen selection purposes.
SCREEN REFLECTION FACTOR:	A screen characteristic which establishes the amount of room light which is reflected by the screen to the observer. The less ambient light reflected, the better the picture contrast in lighted rooms.

To obtain the performance data needed as a basis for the design recommendations, samples of 19 different types of rear projection screens were obtained and each was tested to determine:

1. Screen Gain Characteristics
2. Screen Reflection Factor (S.R.F.)
3. Screen Brightness
4. Maximum Bend Angle
5. Contrast Ratio

The following procedures were used in testing screens:

1. SCREEN GAIN: Nineteen representative screens were obtained from manufacturers, and a Gain Curve was plotted for each screen. All screens were tested in place with actual projection light, consistent with field use. Each was tested as a 4', 5', 6', 7', 8', 9' and 10' screen with gains plotted for the extreme section. Gains were plotted through 70° bend angles for each screen and for each screen size at a projector distance of approximately 2W.

   Input was recorded with a Paddle type Weston foot candle meter, sensitive to 0.1 foot candle. Brightness was recorded with a Spectra Spot brightness meter, calibrated for each reading with a 100 foot lambert fixed brightness source and sensitive to 1 foot lambert with 1-1/2° acceptance angle.

2. SCREEN REFLECTION FACTOR: (S.R.F.) Each screen was tested under three light source conditions (only the low reflection side of the screen was tested).

   a. Projector light (on the room side was used as a specular light source and recorded for angles of reflection from 0° to 70°.
   b. North light was used as a diffuse light source and recorded for angles of reflection from 0° to 70°.
   c. Existing task lighting in the classroom was used as a field condition diffuse light source and recorded for all angles from 0° to 70°.

Close agreement was found between the diffuse North light and classroom task lighting. The diffuse classroom lighting figures are plotted on the Gain Curves for each screen. A 1/4° acceptance Spectra Brightness Meter sensitive to 0.01 foot lamberts, calibrated with a standard source was used for determining Screen Reflection Factors.

3. SCREEN BRIGHTNESS: Screen brightnesses for each screen were recorded for each screen size, projector, projection distance and for each bend angle to a limit of 5 foot lamberts. These figures were used to plot the Screen Gain Curves.

4. MAXIMUM BEND ANGLE: Readings for each screen were read through successive bend angles to a 5 foot lambert reading to locate maximum seating limitations for given screen and projector combinations.

5. CONTRAST: Contrast ratios ranging from 600:1 to 5:1 were examined on selected screens and only the lower limits of ASA standards were adjusted for classroom use. Non-image brightness was measured directly in foot lamberts with projector operating with lens capped and room lighting adjusted with rheostat controls.

Since projector performance is well documented, only eight different projectors were utilized in this study. Variations in projector characteristics were used to study the effects of variable apertures, throw distances, light distribution and fall-off. In this report, specifications for projectors will be based on lumen output and light distribution at the screen for fixed throw distances.

To satisfy the contradictory requirements of minimum bend angles and minimum projector throw distance (space economy), a desirable 3W throw distance was adjusted to 2W as a reasonable compromise. Each projector and lens system was evaluated using the three point system to obtain Average Incident illumination. Since new projector lamps consistently appear to give peak values for about two hours, each projector was rated after at least two hours of operation.

Permissable ambient light levels on the screen are dictated by Contrast Ratios for the poorest position of viewing (all other positions having higher Contrast Ratios) a 30:1 ratio was established as marginal to satisfy reasonably high task light levels.

SECTION IV - STANDARDS

The American Standards Association and detail studies related to viewing projected images have established minimum and maximum professional standards accepted by the S.M.P.T.E. These standards provide excellent images and are included in the following summary of standards. For the purposes of economy in classroom use, certain professional standards have been lowered where an acceptable image for instructional use has been tested and found to be adequate for gross images. (An asterisk is used to denote classroom standards). The selection of the components of a rear projection system are closely interrelated but the final image produced must meet the following standards to provide a satisfactory image.

SCREEN BRIGHTNESS

Motion Pictures:
* 5 ft.L.: Minimum (marginal for some observers)
10 ft.L.: Satisfactory
15 ft.L.: Excellent
20 ft.L.: Maximum (flicker threshold for some observers)

Slides:
1 ft.L.: difficult to distinguish color from black and white
* 2.5 ft.L.: minimum for gross images
5 ft.L.: minimum for slides with detail
10 ft.L.: satisfactory
20 ft.L.: excellent

(Theoretically, the upper limit for slides is the tolerance limit of the eye. For practical purposes economics and projector limitations will control)

Projected TV:
* 2 ft.L.: Gross black and white images
20 ft.L.: Maximum, flicker threshold

TV Monitors:
100 lumens per sq. ft.

Brightness Ratios:
2:1: Excellent. Produces practically a uniform brightness across screen
3:1: Very good. Beyond this, bright spots begin to appear
*10:1: Acceptable. Although "hot spots" are readily apparent.

Contrast Ratio:

100:1	Pictorial scenes
25:1	Good legibility of printed characters
5:1	White letters on black background
*30:1	Recommended minimum contrast ratio for poorest seat, dictated by need for higher levels of room light for instructional use.

Task Light Levels:

Ideally, a 1:1 ratio of task surface brightness and maximum screen brightness is desirable. But since screen brightness varies across a wide range for different observing positions, a value based on an average screen brightness is most reasonable.

See Page 25 for recommended levels.

SECTION V - SELECTION OF COMPONENTS

On the basis of information gathered during this investigation, it is possible to select and specify projectors and screens and establish lighting levels to produce predictable viewing conditions in classrooms and auditoria.

Once understood, the technique of selection of components and prediction of results is relatively straightforward. It is possible to:

1. **Select a specific projector and screen, knowing audience size.**
2. **Determine audience size, knowing screen and projector.**
3. **Predict viewing conditions for each observer with any combination of the above.**

Since this project is limited to the analysis of eight case studies, the following design example will be based on similar given conditions.

Design Conditions

Known:
1. Fixed audience size: 60 seat classroom
2. Edge angle (distortion limit): 40°
3. Minimum seating distance: 2W
4. Maximum seating distance: 6W
5. Screen width: W = 5'-0" (determined by depth of sector (6W) required to seat 60 occupants

Required:
1. Selection of trial screen
2. Selection of projector throw distance
3. Plot of gain ratios for given auditorium and screen
4. Determination of brightness levels and projector output
5. Computation of Ambient light level for contrast
6. Determination of task lighting level
7. Summary of viewing conditions

Design

A - Selection of Trial Screen

- The selection of a screen is affected by each of the 9 factors listed by Vlahos in Section 1 of this report. With such a large number of variables a monograph or graph procedure would simplify selection. Fortunately, certain design limitations narrow the number of possible screens very quickly.

- Examination of the gain curves (see Appendix) shows that five characteristics will dominate in selecting a screen for an auditorium whose sector angle is greater than 50°.

  1. Maximum gain.
  2. Gain at maximum bend angle (MB Angle)
  3. Screen brightness.
  4. Brightness ratio.
  5. Screen reflection factor (SRF) at maximum bend angle.

- Figure I lists these characteristics for six screens chosen as representative of the group of 21 screens tested. A brief explanation of the influence of these characteristics follows:

FIGURE 1

SCREEN NO.	MAXIMUM GAIN	GAIN MB4 = 62°	SCREEN BRIGHTNESS gain x input = 5	BRIGHTNESS RATIO	S R F MB4
11	0.46 p	0.40 g	12.5 ft.c. g	1.2:1 e	50% p
10	1.35 f	0.41 g	12.4 ft.c. g	2.9:1 e	45% p
9	1.70 f	0.19 p	26.4 ft.c. p	4.9:1 g	17% f
14	2.30 g	0.32 f	16.0 ft.c. f	4.8:1 g	24% f
8	2 90 g	0.22 p	23.0 ft.c. p	9:1 p	15% g
3	6.90 e	0.08 u	62.0 ft.c. u	6 9:1 u	5.8% e

1. Maximum Gain:

- Since a screen is a passive element and serves only to transmit and diffuse light output, every gain for one sector must be compensated for with an equal loss in another. (Also, the screen efficiency is, at best, about 60% in transmitting light).

- Where the viewing angle is relatively narrow (25° or less) this light may be concentrated into a narrow cone to produce high brightness with low input.

- Where the viewing angle is wide (60° or more) the loss of brightness at the edges (MB angle) becomes the controlling factor.

- GENERALLY: For wide viewing angles, the closer a gain curve approximates a flat curve with a uniform gain of 1, the better will be its overall performance.

2. Gain @ MB angle:

- Minimum brightness levels occur along this line of vision.

- To achieve maximum brightness with minimum input, gain here should be as high as possible.

3. Screen Brightness:

- Section IV (STANDARDS) establishes minimum and maximum brightness levels.

- Screen Brightness = Gain x Input. For economy, the higher the gain, the less the input required to achieve a specified brightness level.

- Figure I shows the input in ft.C. required to produce a brightness level of 5 ft.L.

4. Brightness Ratio:

- Section IV (STANDARDS) establishes desirable brightness ratios.

- Ideally, ratios of 3:1 are desirable but ratios up to 10:1 are acceptable.

5. S.R.F. @ M.B. Angle:

- Permissable ambient light on the screen, and the corollary task lighting levels are determined by the reflected light along this line of vision.
- UNLESS relatively high screen brightness occurs along this line of vision, the SRF should be as low as possible.

Selection:

- The letters in Figure 4 rate the various screens for each of these factors:

E = Excellent
G = Good
F = Fair
P = Poor
U = Unexceptable for wide sectors

- Unless some special way of controlling ambient light is introduced, screens 10, 11, and 14 will require very low task light levels to satisfy contrast ratios.
- Screen 3 is unacceptable.
- Either Screen 8 or 9 may be tried. Because of lower input, Screen 8 has been chosen for the first trial.

B. Projector Throw Distance:

- The location of the projector behind the screen must satisfy two opposing requirements:

  1. The longer the throw distance, the less the Maximum Bend Angle to any observer.
  2. The longer the throw distance, the more expensive the space behind the screen becomes.

- If space economies are not a problem, a throw distance of 3W is desirable to control MB angle.
- If space economies are a problem, a throw distance of 1-1/2 to 2W is a reasonable compromise.
- For the SUNY studies, a throw distance of 2W is standard.

C. Procedure for Plotting Gain Ratios:

- General - The difference in brightness on the screen is a source of distraction to the observer. This difference is described by the brightness ratio between the brightest spot to the least bright spot as seen by any given observer. Since brightness and gain follow a linear relationship this condition may be described as a GAIN RATIO.

- The reference axis for bend angles is the ray of the projector at 5% from the screen edge. Since this ray forms a different angle with each different projector-distance, a Gain Ratio Plot should be made for each change in projector distance and screen. For this project, a constant 2W is used. Therefore, only one plot is required for each screen and will be suitable for any projector or any classroom size.

- Procedure:

1. For convenience, on an overlay of the auditorium plan layout the screen (W) and projector at (2W). (Fig.2)

2. Extend projector rays through Center Line and 5% points. (Fig. 3a) a,b,c.

3. The gain characteristics are the same for the screen at points a, b, and c; but the foot candle "input" is greater at "a" than at "b" and "c". By adjusting the gain at "b" and "c" by the fall-off factor (F-F) of the projector, "a" may be expressed as a function of "b" or "c". For certain slide projectors a = (1.5 x b) (Kodak Carousel).

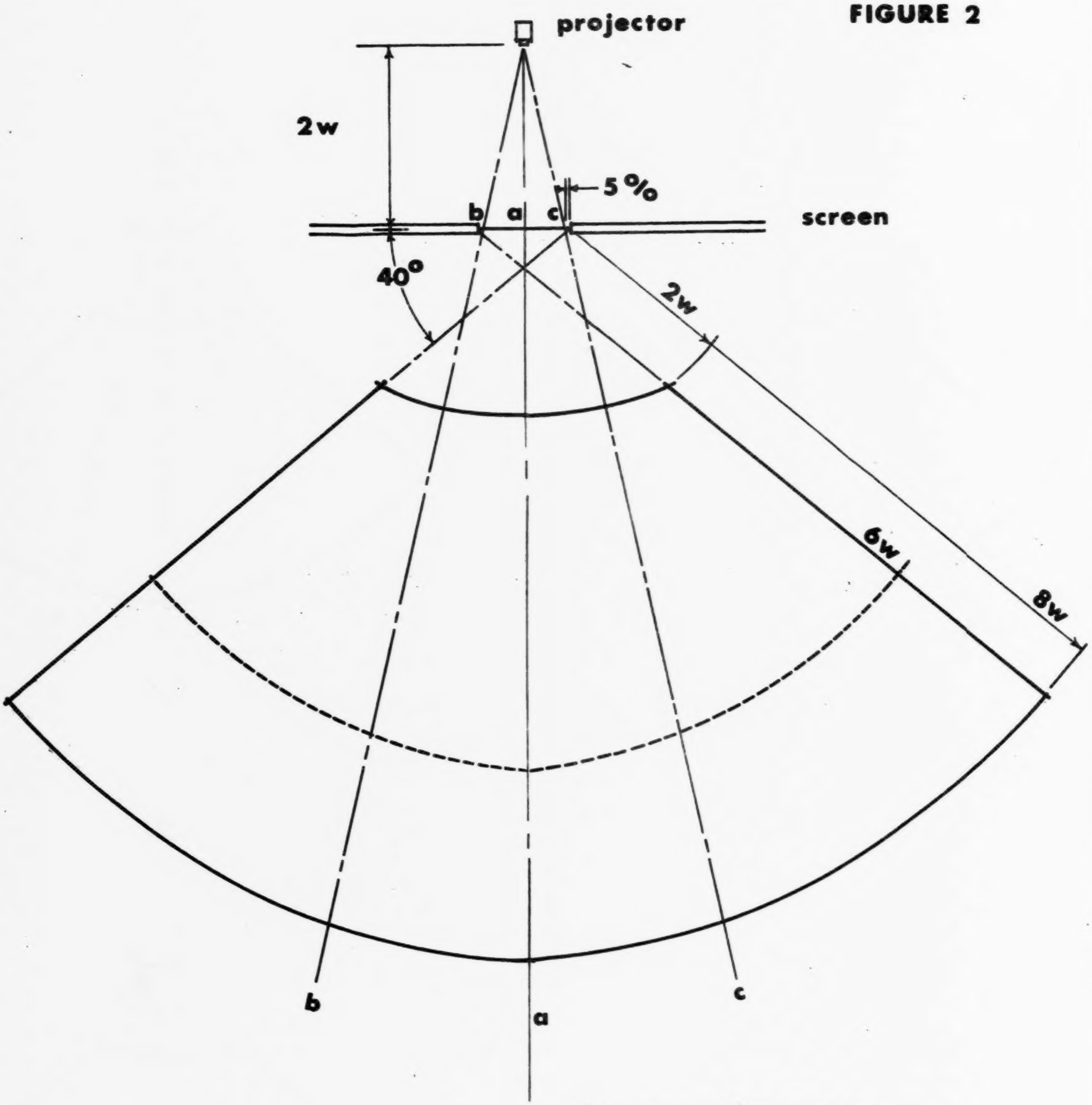
4. By direct proportion determine 1/4 points d, e, f. (Fig. 3b) From the gain curve for Screen 8 determine "b", and since "a" = 1.5 times "b" determine "a". By proportion determine "d-e-f".

5. At points "b" lay out 10° bend angles to include only 1/2 auditorium. Assign Gain values from Gain Curve (Fig. 3c)

6. At point "c" lay out 10° bend angles to include same half of auditorium. Assign gain values from Gain Curve.

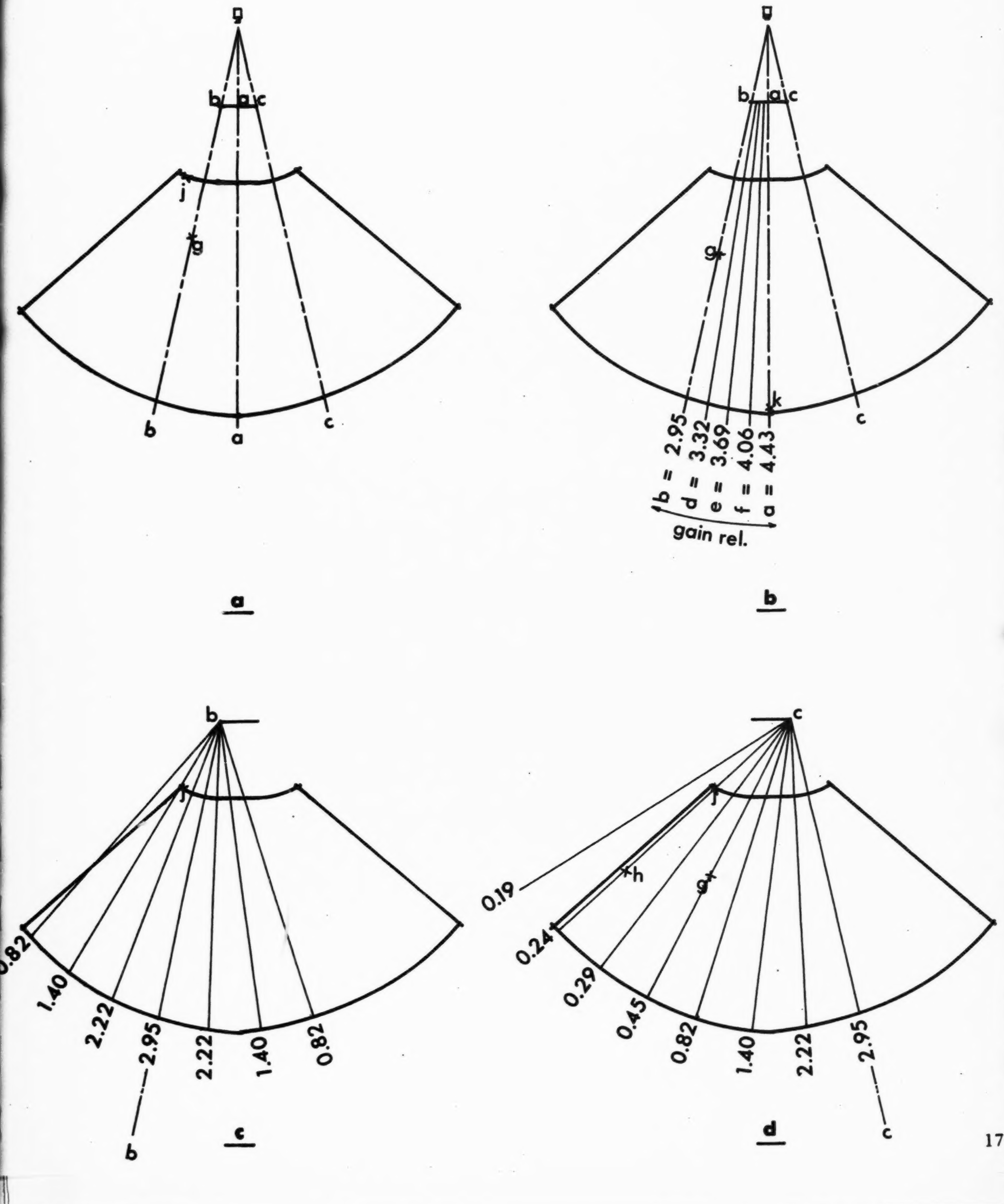
7. The gain ratio for any observer station (g) is the relation of the highest gain sight line to the lowest $\frac{2.95}{0.45} = 6.6$ (Fig. 3e)

FIGURE 2


projector
2w
5 %
b
a
c
screen
40°
2w
6w
8w
b
a
c

60 seat classroom
scale 1/8" = 1'-0"

FIGURE 3


o
b
a
c
j
g
b
a
c
o
b
a
c
g
k
c
b = 2.95
d = 3.32
e = 3.69
f = 4.06
a = 4.43
gain rel.
b
j
.82
1.40
2.22
2.95
2.22
1.40
0.82
b
c
j
h
g
0.19
0.24
0.29
0.45
0.82
1.40
2.22
2.95
c

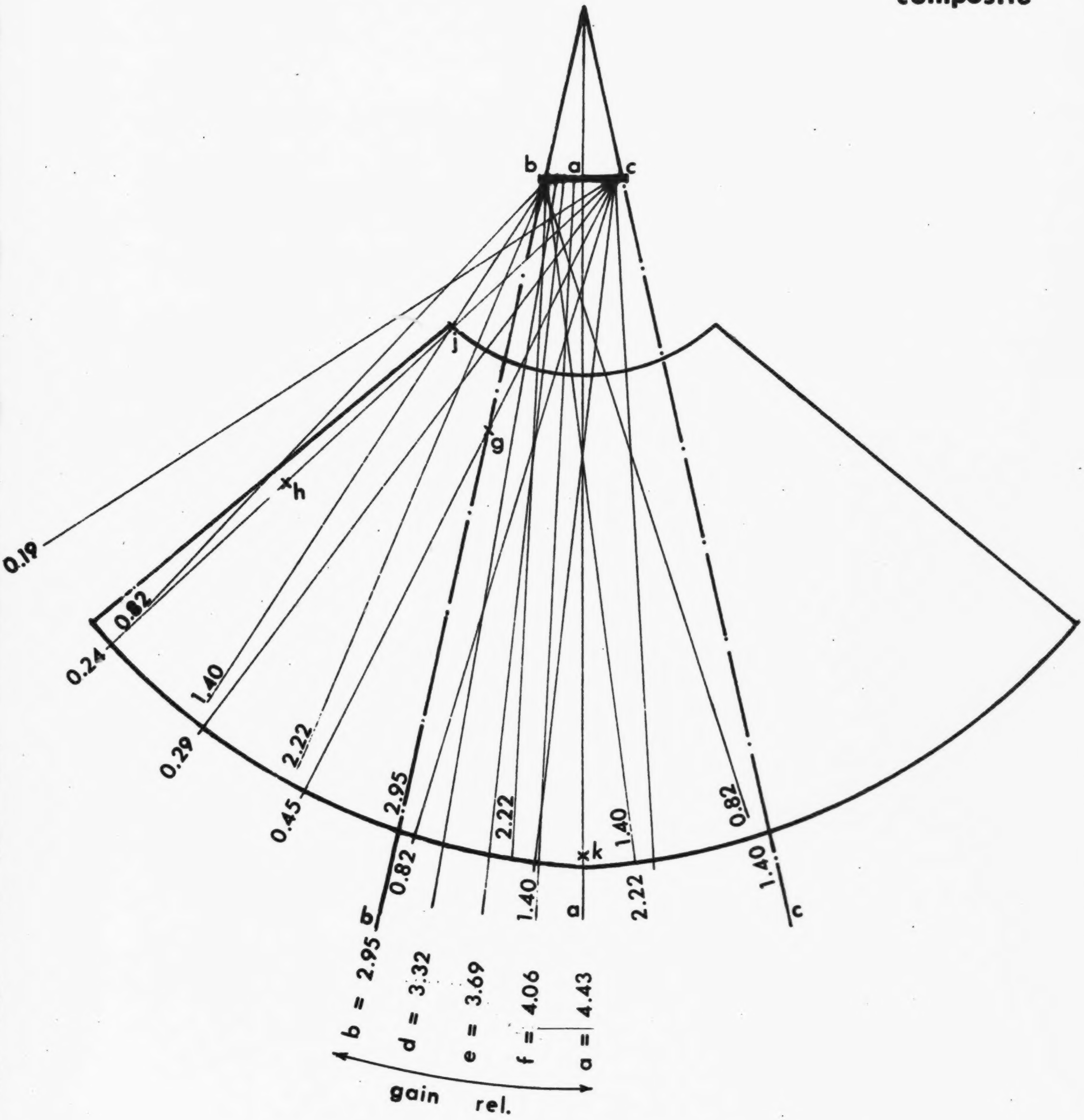
a

b

c

d

FIGURE 3e
composite


b
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0.19
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0.82
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1.40
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0.82
1.40
2.22
b
a
c
b = 2.95
d = 3.32
e = 3.69
f = 4.06
a = 4.43
gain rel.

8. Plotting a sufficient number of points will produce a brightness contour layout similar to (Fig. 4)

9. All seats occuring within "A" areas are excellent with a brightness ratio of less than 3:1.

   "B" - Fair with all seats between 6:1 and 3:1
   "C" - Poor, all seats between 10:1 and 6:1

D. Brightness Level and Projector Output

1. The brightness at any seat is also obtained from the gain ratio layout, for the seat "g" the highest gain is 2.95 and the lowest 0.45. Since Brightness = Gain x (ft.C. "input"), if the "input" is known the brightness or brightness ratio is easily computed.

2. Conversely, if the gain at any seat is known the ft.C. "input" for a given brightness may be computed.

$$\text{ft.C. (input)} = \frac{\text{brightness}}{\text{gain}}$$

3. Since minimum brightness for seat "h" (Fig. 3e) will occur along the sight line "h-c", if a minimum brightness of 5 ft.L. is required at "h", a ft.C. (input) $= \frac{5}{0.24}$ = 20.8 ft.C. is required at "c" and "b".

4. Since a = 1.5b, "a" input for a Carousel would be 31.2 ft.C.

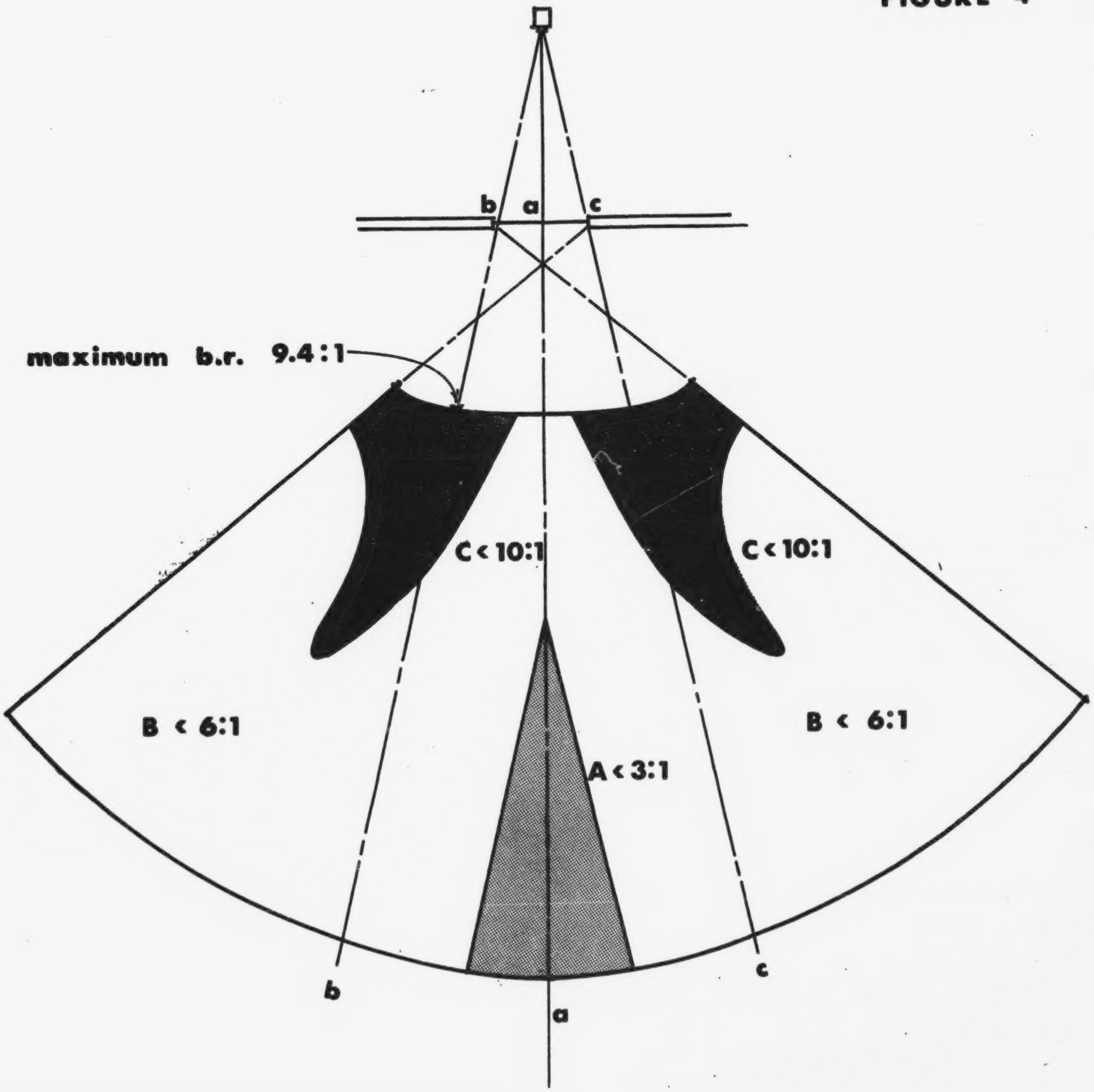
5. Required PROJECTOR LUMEN OUTPUT using the three point method is:

   P.L.O. (lumens) = Average "input" (ft.C.) x picture size.

$$\text{P.L.O.} = \frac{20.8 + 31.2 + 20.8}{3} \times 25 = 608 \text{ Lumens}$$

6. It should be noted that bend angle in these computations is taken in a horizontal plane only. Actually, vertical bend angles have the identical effect, so that maximum bend angle is actually to the farthermost light ray, horizontally and vertically. Since critical information is presented within a radius equal to 1/2W or less of the center of the screen, this effect may be safely ignored.

FIGURE 4


b
a
c
maximum b.r. 9.4:1
C < 10:1
C < 10:1
B < 6:1
B < 6:1
A < 3:1
b
a
c

contour layout of
brightness ratios

E. Ambient Light:

- The relationship between the brightest possible portion of an image and the darkest portion (black) is called the CONTRAST RATIO. Since the level of "blackness" which can occur is limited by the amount of ambient light reflected from the screen, the lower level is established by the NON-IMAGE BRIGHTNESS.

- $$\text{Contrast Ratio} = \frac{\text{Image Brightness}}{\text{Non-image Brightness}}$$

  1. Seat "j" in Fig. 3 is the most critical seat. Its maximum brightness occurs at a bend angle of 18° from point "b". Its minimum brightness occurs at a bend angle of 60° from point "c". From the gain curve "j" = 0.24 x 20.8 = 5 ft. L.

  2. If the contrast ratio at this seat is held to 30:1 then $\frac{5}{30}$ or 0.167 ft.L. of non-image brightness is permitted at seat "h" from Point "c".

  3. If no stray light is assumed on the rear of the screen:

     Reflected light at seat "j" (ft.L.) =
     Incident light at point "c" (ft.C.) x
     S.R.F. at 45° (angle of seat "j") =
     0.167 (ft.L.) = "c" (ft.C. x 0.12)

     Incident light = 1.4 ft.C. of ambient light on screen.

F. Task Lighting:

- On the basis of required input the best seat in the classroom is seat "k" (Fig. 3e)

  $$\text{BRIGHTNESS RATIO} = \frac{4.43}{1.7} = \underline{2.6}$$

  BRIGHTNESS LEVEL = 4.43 x 31.4 = 139 ft.L.

  $$\text{CONTRAST RATIO} = \frac{139}{0.12 \times 1.4} = 829:1$$

- The poorest seat is seat "j"

  $$\text{BRIGHTNESS RATIO} = \frac{1.6}{0.24} = 6.7$$

  BRIGHTNESS LEVEL = 0.24 x 20.8 = 5 ft.L.

  CONTRAST RATIO = 30:1

- The "average" value for task lighting = 139 + 5÷2 = 72 ft.C. (see Standards)

G. Summary of Viewing Conditions:

- The preceeding computation establishes conditions within the viewing area on the basis of required Projector Lumen Output. Actually, a standard Carousel has a lumen output of 930 lumens, for 1.5" x 1.5" aperture. The actual input at points a, b, and c, would become a = 48 (ft.C.), "b" and "c" 32 ft.C.

- Therefore, with a Number 8 screen and a standard Carousel, the comparable viewing conditions would be:

  1. Minimum Brightness at "j" = 7.7 (ft.L.)
  2. Permissable N.I. Brightness at "j" = 0.256 (ft.L.)
  3. Incident light on screen = 2.14 ft.C.
  4. Brightness Ratio for "k" = 2.6
  5. Brightness Ratio for "j" = 6.7
  6. Brightness Level for "k" = 213 (ft.L.)
  7. Brightness Level for "j" = 7.7 (ft.L.)
  8. Contrast Ratio for "k" = 830:1
  9. Contrast Ratio for "j" = 30:1

- On the basis of these computations, the screen would perform adequately.

- A screen with a lower peak gain and flatter curve would improve the poorer seats.

- A projector with less lumen output could be substituted.

- If less task lighting is permissable, a screen with higher Reflection Factor and lower Peak Gain could be used.

H. Various general observations have also resulted from this investigation:

   1. Reflection characteristics of adjacent wall, floor and desk surfaces effect screen ambient light seriously.

   2. Cove lighting, if used at all, must be carefully controlled to avoid specular images.

   3. Use of mirrors seriously impairs total light available at screen and greatly increases rear ambient light levels.

4. Flexible screens may be used in any size with independent glass backing at only 10% light losses.

5. Careful maintenance of projector, mirrors, and screen is critical since dust, grime and lamp oxidation severely impair performance.

6. Manufacturers information on screen gain and projector performance must be adjusted to "in-use" figures.

7. Specification of projectors on the basis of Lumen output only does not recognize quality of projector as a selection factor. Initial cost, life expectancy, maintenance, reliability and replacement should be considered.

8. Screen selection for this study is based on gain curves obtained from random samples. Gain characteristics for a given screen may vary ± 20 %, therefore, in any specifications for a screen: the 0° Bend Angle value should be considered as maximum, and the 60° Bend Angle value should be considered as a minimum.

9. Ideally, a rear projection screen should have a flat gain curve equal to 1 at all bend angles.

10. Ideally, a projector should have no falloff in output from center to edge. If anything, there should be an increase in output from center to edge of screen.

All tests were conducted in the controlled environment of the Experimental Classroom at Rensselaer.

Verification:

After testing all components, a design procedure was established. Then two conditions were designed for the Experimental Classroom's two screens. One series of components was selected to provide EXCELLENT viewing for all seats in the classroom and set up on one screen. A second series of components was selected to provide MARGINAL viewing in selected seats and set up on the second screen. The images were compared and readings taken for maximum and minimum areas in the classroom. The readings in each case were consistent with design predictions.

Application:

On the basis of this information, 5 basic classroom types ranging from 60 to 480 seats were analyzed and components selected to provide predicted viewing conditions.

(See following section).

SCREEN PERFORMANCE SPECIFICATION

Gain @ 0°	1.8Max 0.8Min
Gain @ 60°	0.4Min
Resolution - Line Pairs/MM	12 Min
Reflection Factor @ 60°	35%Max.

PROJECTOR SELECTION AND AMBIENT LIGHT LEVELS

Study #	No.of Seats	Throw Distance	Screen Size	Projector Selected	A.A.L.on Screen *
1	60	10'	5'x10'	Carousel Std	1.4 ft.c.
				Jan Std	0.8 ft.c.
2	120	14'	7'x14'	Carousel Std	0.7 ft.c.
				Jan W/Xenon	1.4 ft.c.
3	120	10.5'	7'x14'	Carousel Std	0.6 ft.c.
				Jan W/Xenon	1.3 ft.c.
4	240	16'	8'x24'	Carousel W/Xenon	1.3 ft.c.
				Jan W/Xenon	1.0 ft.c.
5	240	12'Side	8'x24'	Carousel W/Xenon	1.2 ft.c.
		16'Ctr		Jan W/Xenon	1.0 ft.c.
6	360	18'	9'x27'	Carousel W/Xenon	1.0 ft.c.
				Jan W/Xenon	0.7 ft.c.
7	360	13.5'Side	9'x27'	Carousel W/Xenon	0.9 ft.c.
		18'Ctr		Jan W/Xenon	0.7 ft.c.
8	480	20'	10'x30'	Carousel W/Xenon	0.9 ft.c.
				Jan W/Xenon	0.6 ft.c.
9	480	15'Side	10'x30'	Carousel W/Xenon	0.8 ft.c.
		20'Ctr		Jan W/Xenon	0.6 ft.c.

RECOMMENDED PROJECTION EQUIPMENT

Manufacturer	Lumen Output
Eastman-Kodak Carousel (Std)	932[1]
Bell & Howell Jan (Std)	375[2]
Eastman-Kodak Carousel W/450W Xenon	2300[1]
Bell & Howell Jan W/450W Xenon	1200[2]

1. With 2x2 superslide aperture
2. Gate running, no film in aperture

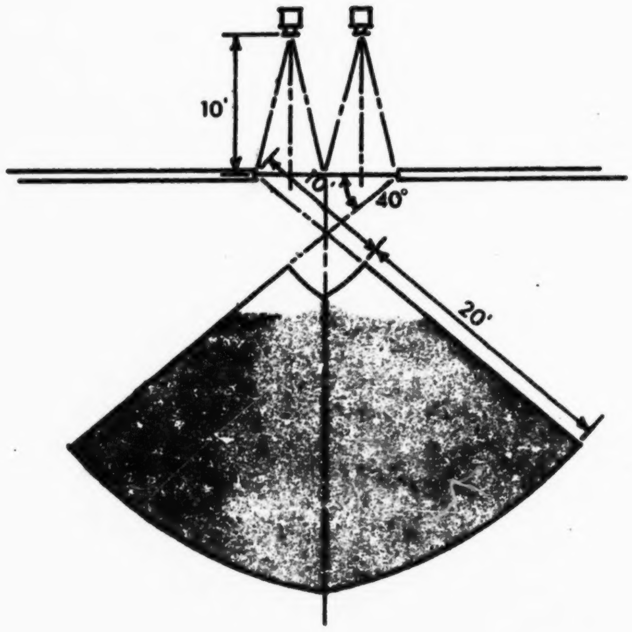
RECOMMENDED TASK SURFACE LIGHTING LEVELS

The following minimum values tend to be fairly arbitrary. The recommendations, however, may be considered satisfactory for reading and writing at the task surfaces:

7 ft.C.:	TV film
15 ft.C.:	Slides
45 ft.C.:	General room illumination for lecturing

* Allowable ambient light (A.A.L.) decreases 10% if projection is through glass to flexible screens.

60 SEAT ROOM
scale: 1"= 16'



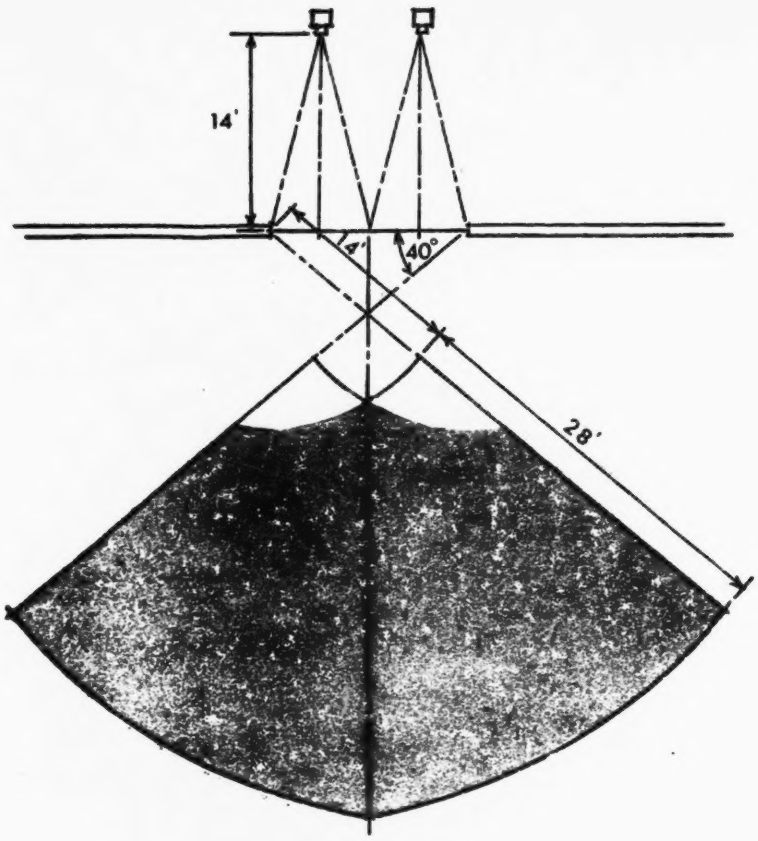
Projector
Lumen Output
35MM - 932
16MM - 375

Screen Size 5'x10'

A.A.L.
35MM 1.4 Ft.C.
16MM 0.8 Ft.C.

STUDY #1

120 SEAT ROOM
scale: 1"= 16'

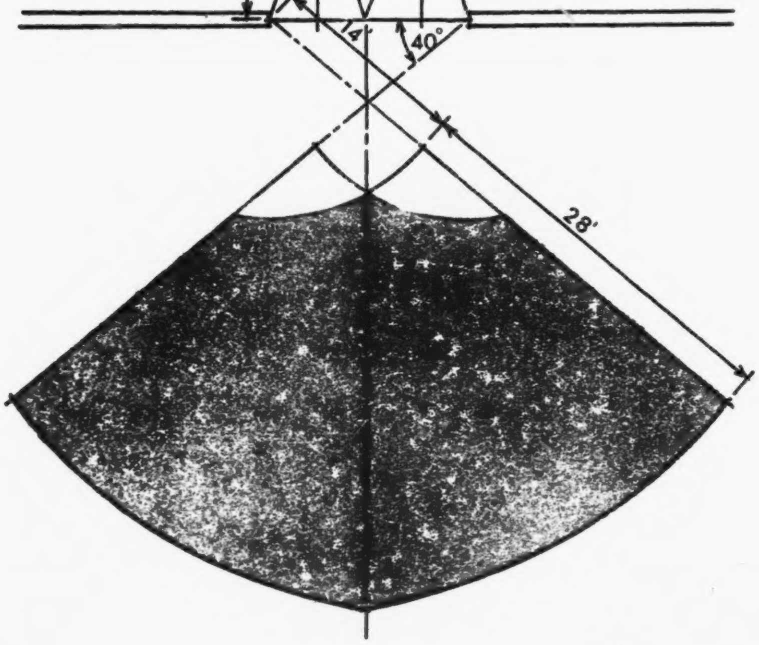


Projector
Lumen Output
35MM - 932
16MM - 1200

Screen Size 7'x14'

A.A.L.
35MM - 0.7 Ft.C.
16MM - 1.4 Ft.C.

STUDY #2



Projector
Lumen Output
35MM - 932
16MM - 1200

Screen Size 7'x14'

A.A.L.
35MM 0.6 Ft.C.
16MM 1.3 Ft.C.

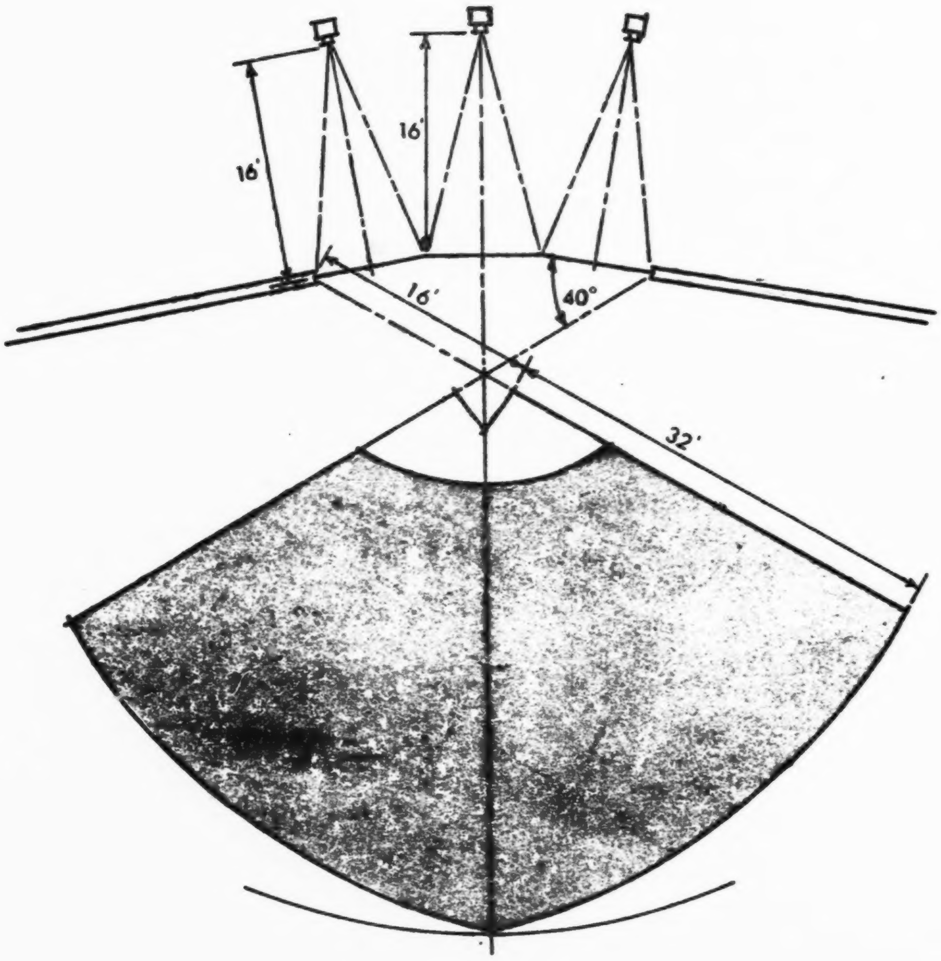
STUDY #3

240 SEAT ROOM
scale: 1"= 16'

Projector
Lumen Output
35MM - 2300
16MM - 1200

Screen Size 3 @ 8'x8'

A.A.L.
35MM 1.3 Ft.C.
16MM 0.9 Ft.C.



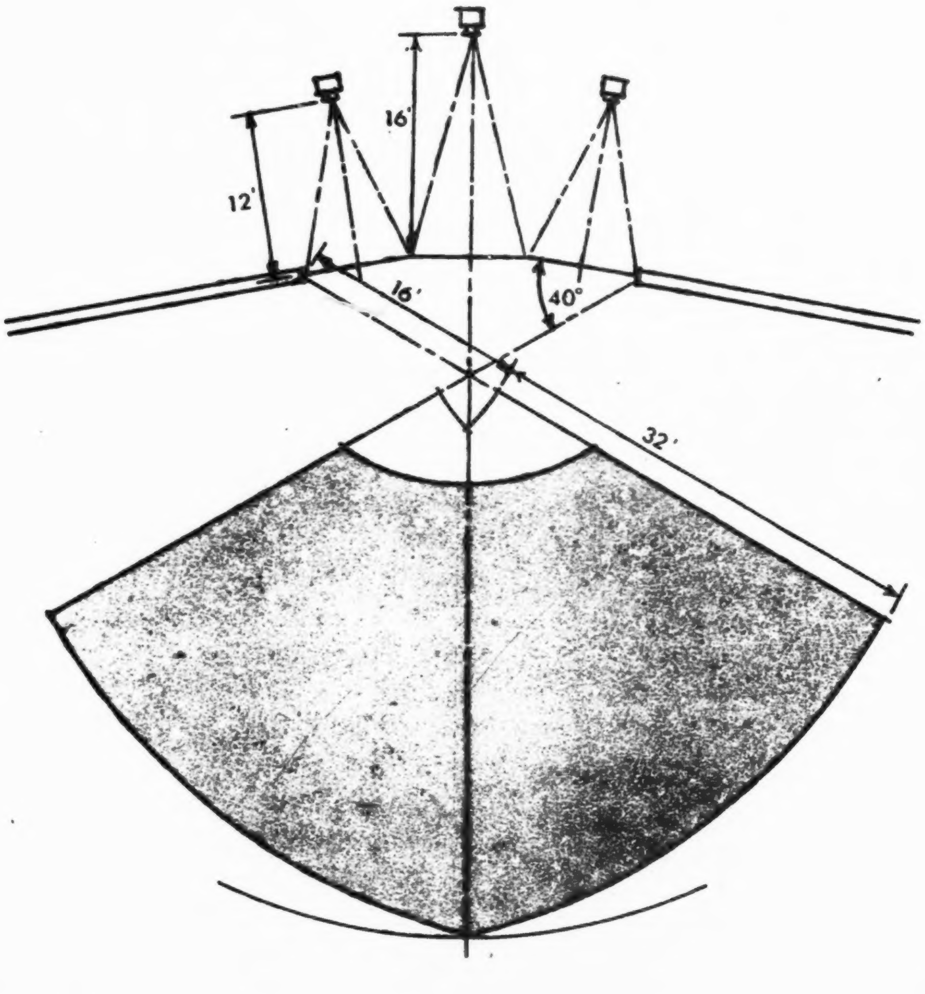
STUDY #4

240 SEAT ROOM
scale: 1"= 16'

Projector
Lumen Output
35MM - 2300
16MM - 1200

Screen Size 3 @ 8'x8'

A.A.L.
35MM 1.2 Ft.C.
16MM 9.9 Ft.C.



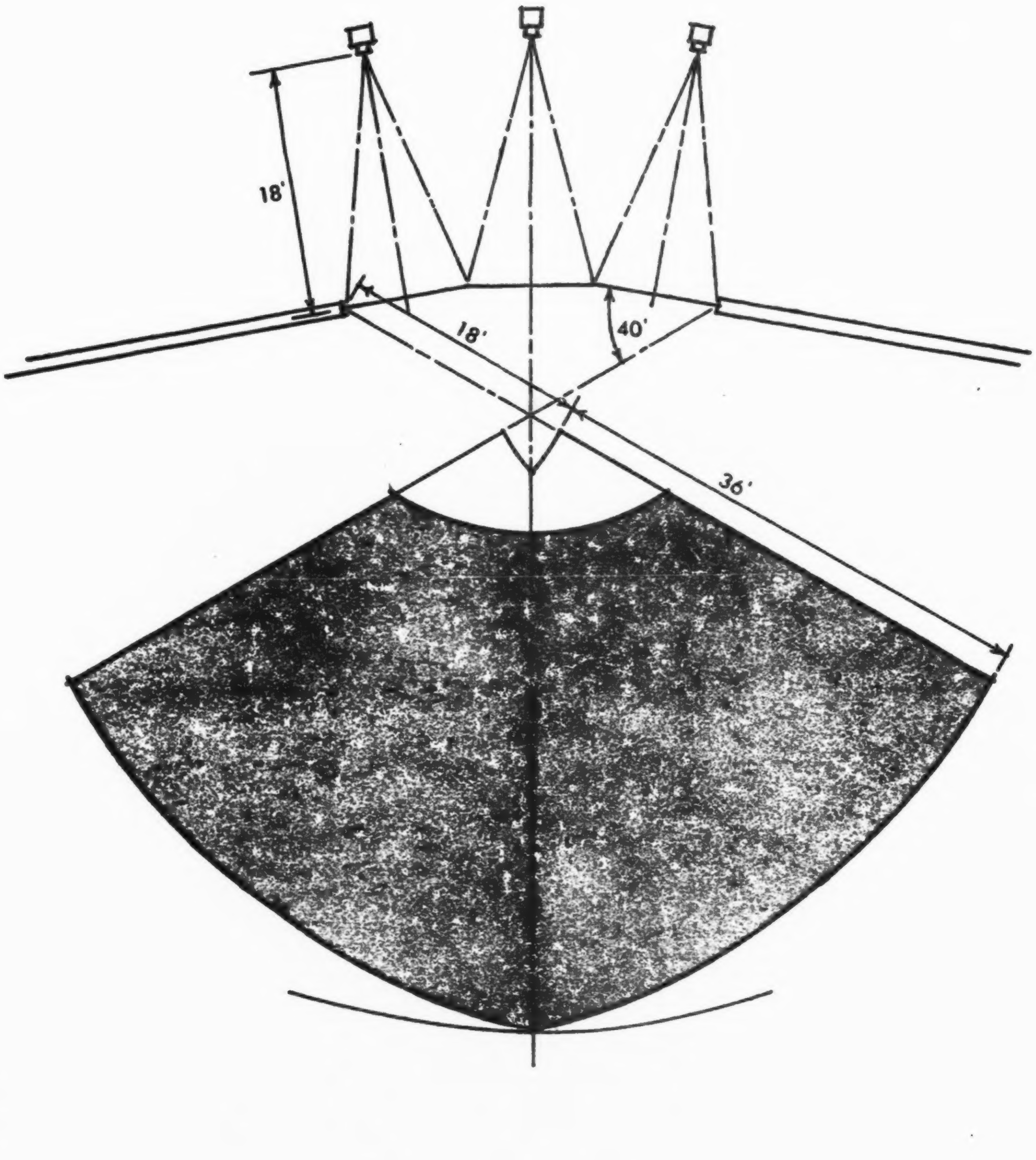
STUDY #5

360 SEAT ROOM
scale: 1"= 16'

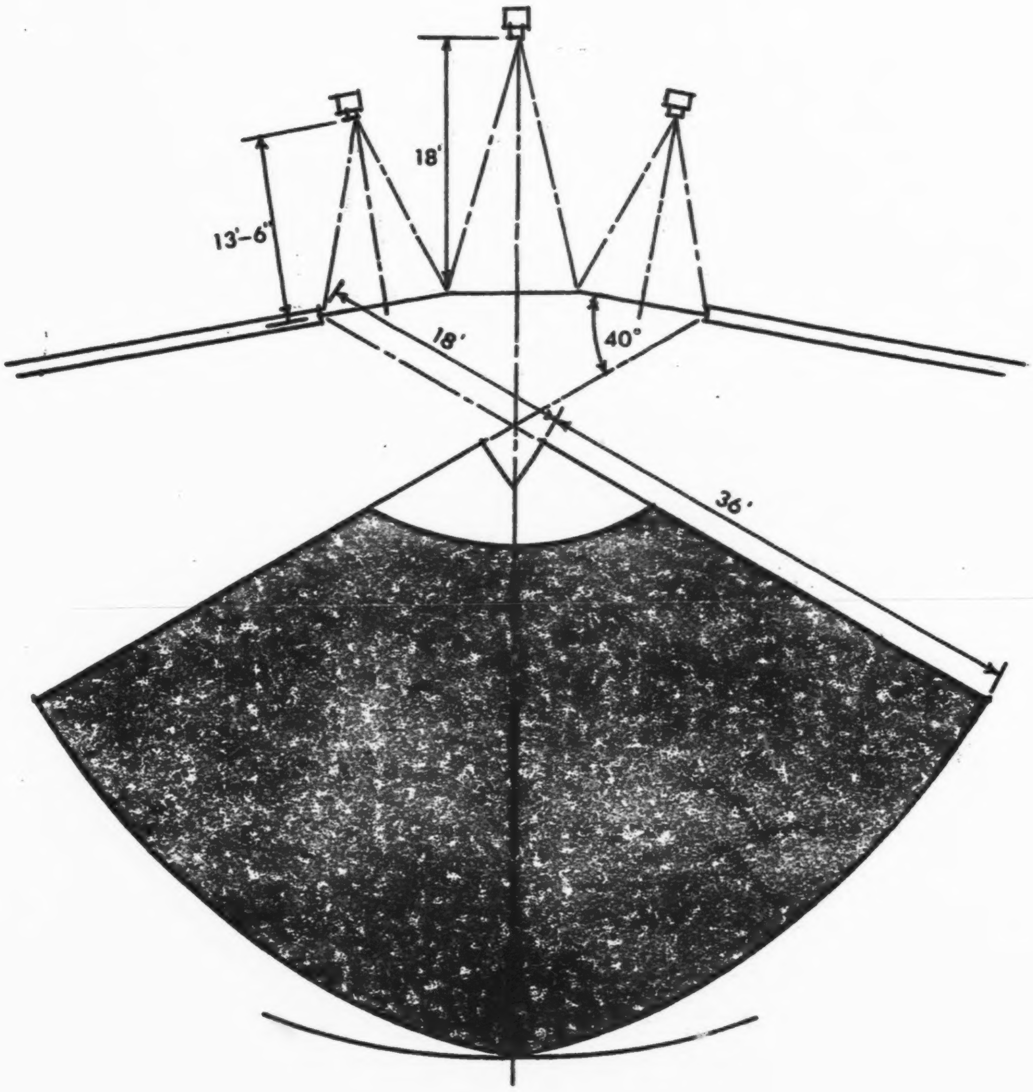
Projector
Lumen Output
35MM - 2300
16MM - 1200

Screen Size 3 @ 9'x9'

A.A.L.
35MM 1.0 Ft.C.
16MM 0.8 Ft.C.



STUDY #6


18'
13'-6"
18'
40°
36'

360 SEAT ROOM
scale: 1"= 16'

Projector
Lumen Output
35MM - 2300
16MM - 1200

Screen Size 3 @ 9'x9'

A.A.L.
35MM 1.0 Ft.C.
16MM 0.7 Ft.C.

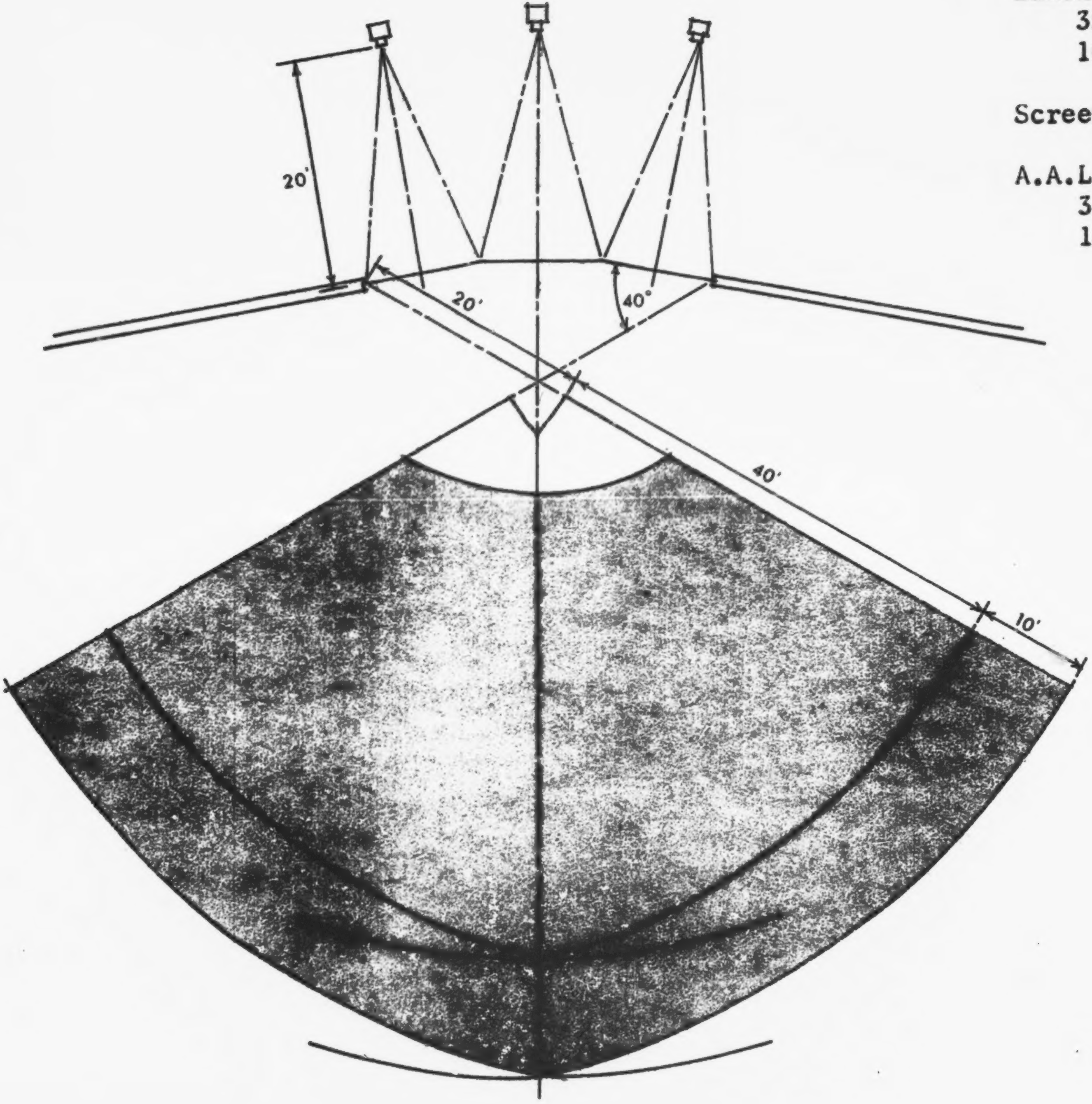
STUDY #7

480 SEAT ROOM
scale: 1"= 16'

Projector
Lumen Output
35MM - 2300
16MM - 1200

Screen Size 3 @ 10'x10'

A.A.L.
35MM 0.9 Ft.C.
16MM 0.6 Ft.C.



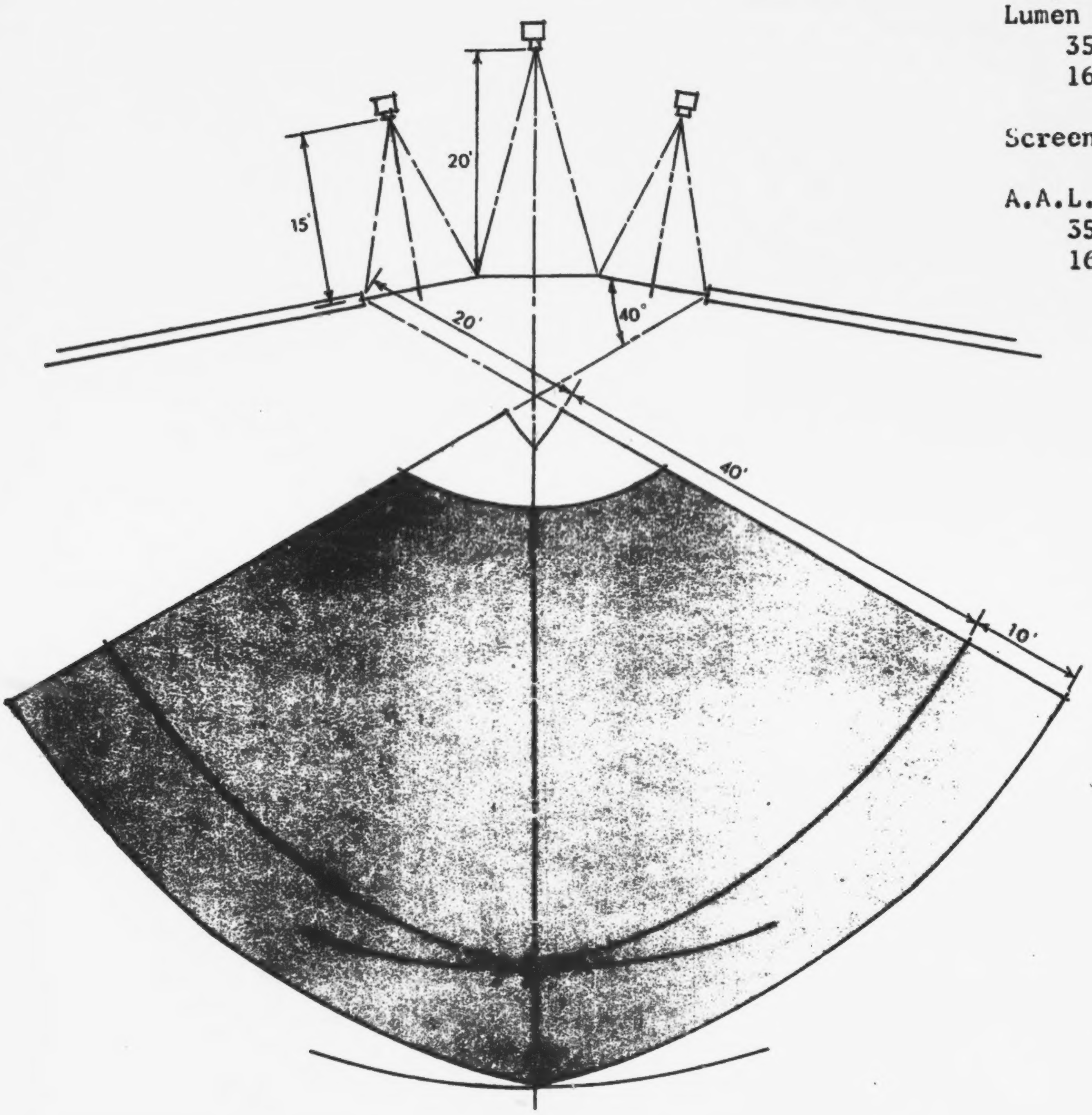
STUDY #8

480 SEAT ROOM
scale: 1"= 16'

Projector
Lumen Output
35MM - 2300
16MM - 1200

Screen Size 3 @ 10'x10'

A.A.L.
35MM 0.8 Ft.C.
16MM 0.6 Ft.C.


20'
15'
20'
40°
40'
10'

STUDY #9

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Projection Lumen Output; Polacoat, Inc.

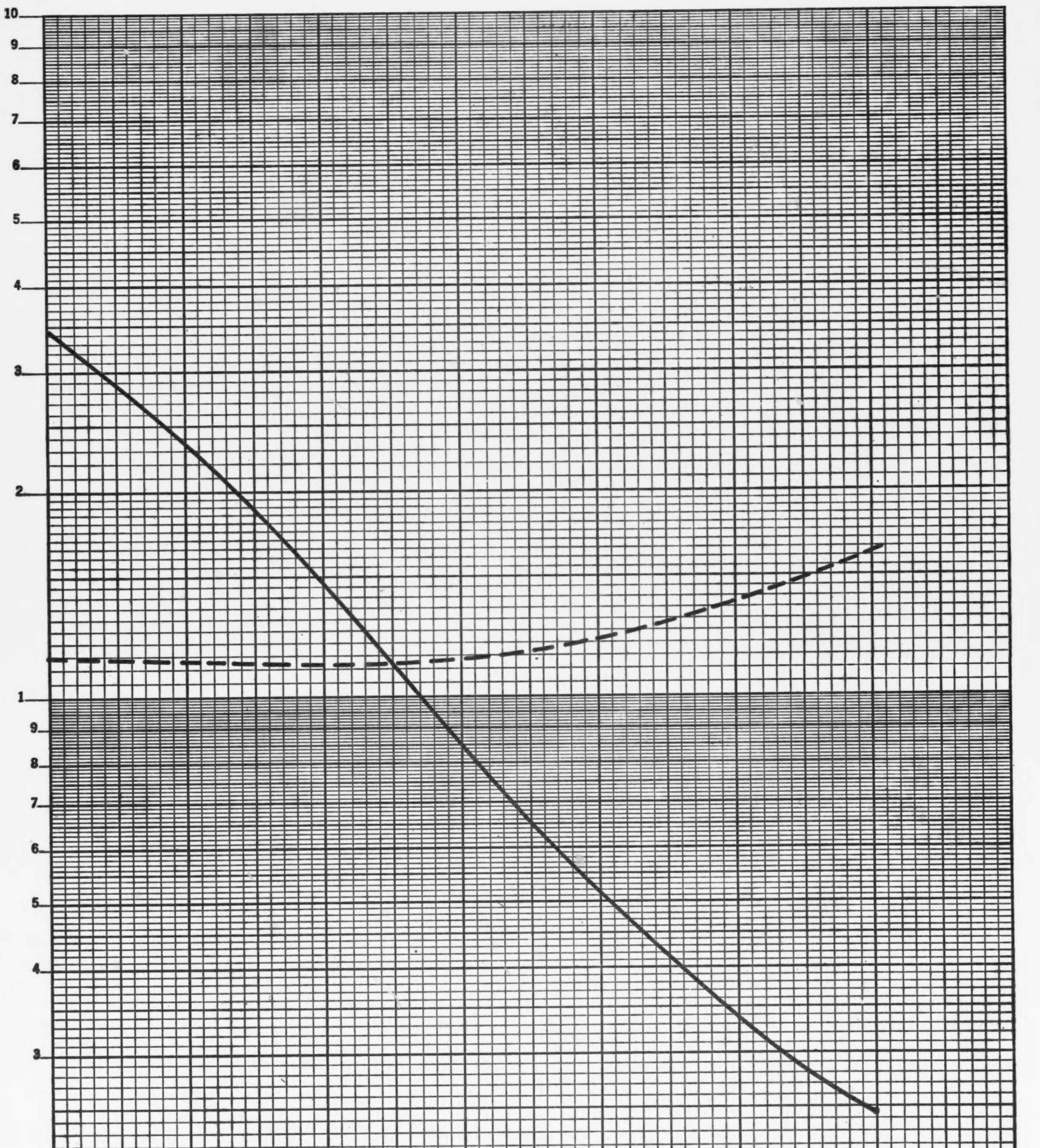
Foundation for Effective Audio-Visual Projection; Eastman Kodak Co.; 1957.

APPENDIX

LIST OF PROJECTION SCREENS TESTED

Green Type 4R White Type 1 Black Type 4	Eastman Kodak Co. Inc. Rochester, N. Y.
LS 60 180 G LS 60 120 G TR 50 PL LS 60 G OC 50 A	Polacoat, Inc. Blue Ash, Ohio
S 50 G S 50 R Luxchrome 50 Luxchrome 70 Forsythe 54 Hi-Trans Type Black Process Flexlume Colorwall TV Blue	Trans-Lux Corp. 625 Madison Avenue New York, N. Y.
Pola-Vu (PV-60)	Commercial Picture Equip. Inc. 1800 West Columbia Chicago, Ill.

The following graphs showing the gain and reflection characteristics of the tested screens are included merely to show the broad range of products available today. The numbers on the graphs do not coincide with the above list.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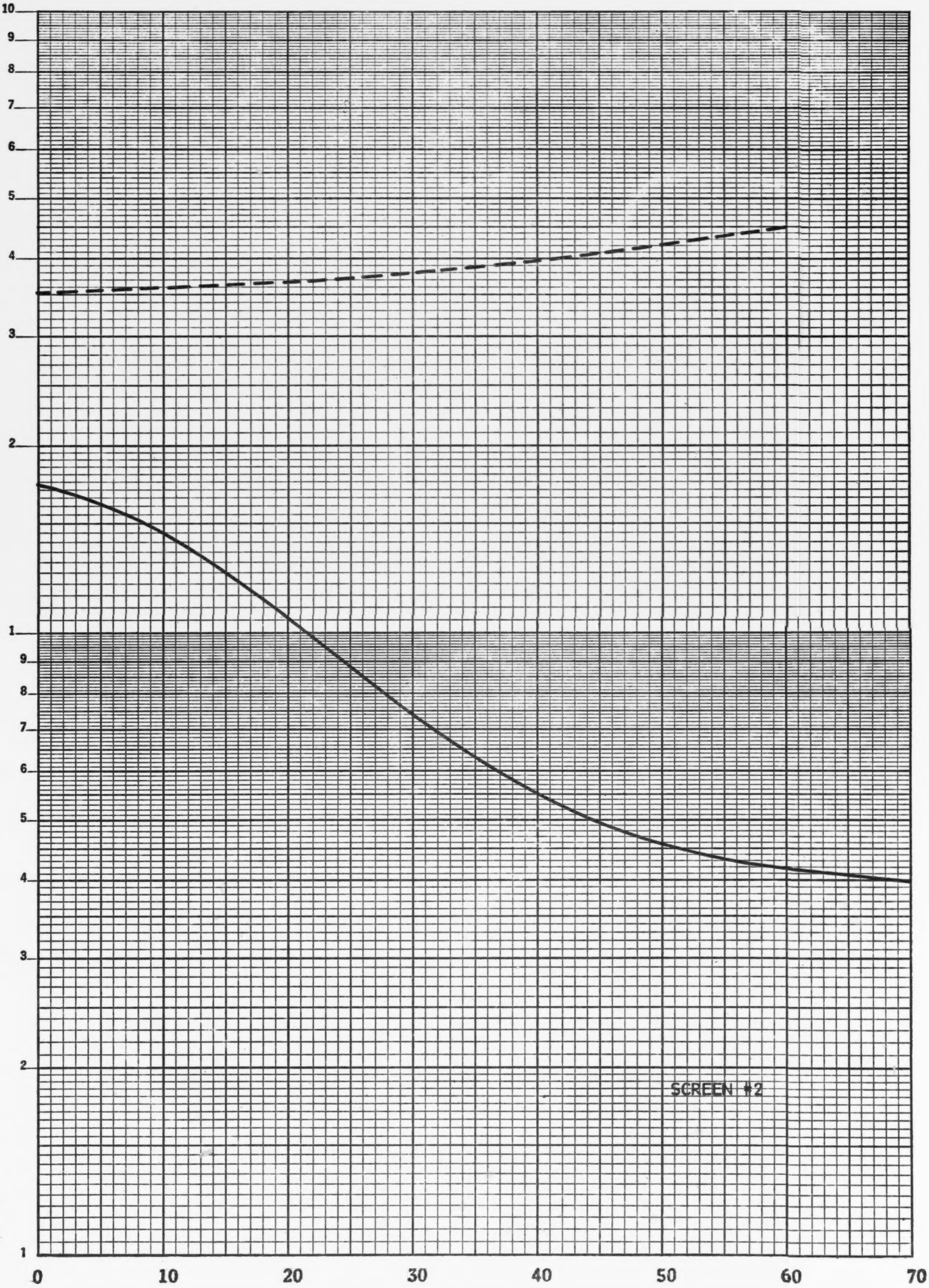
SCREEN #1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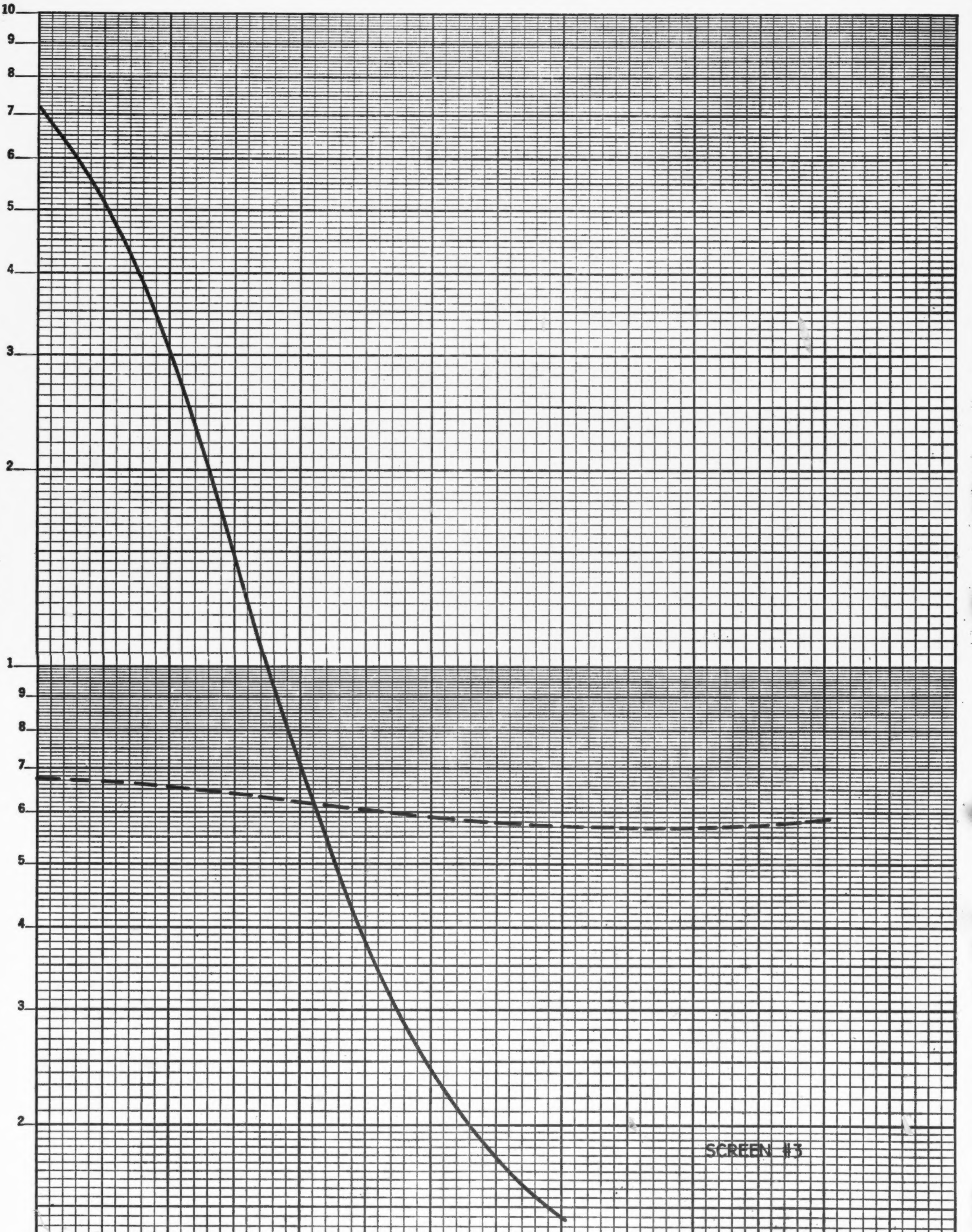
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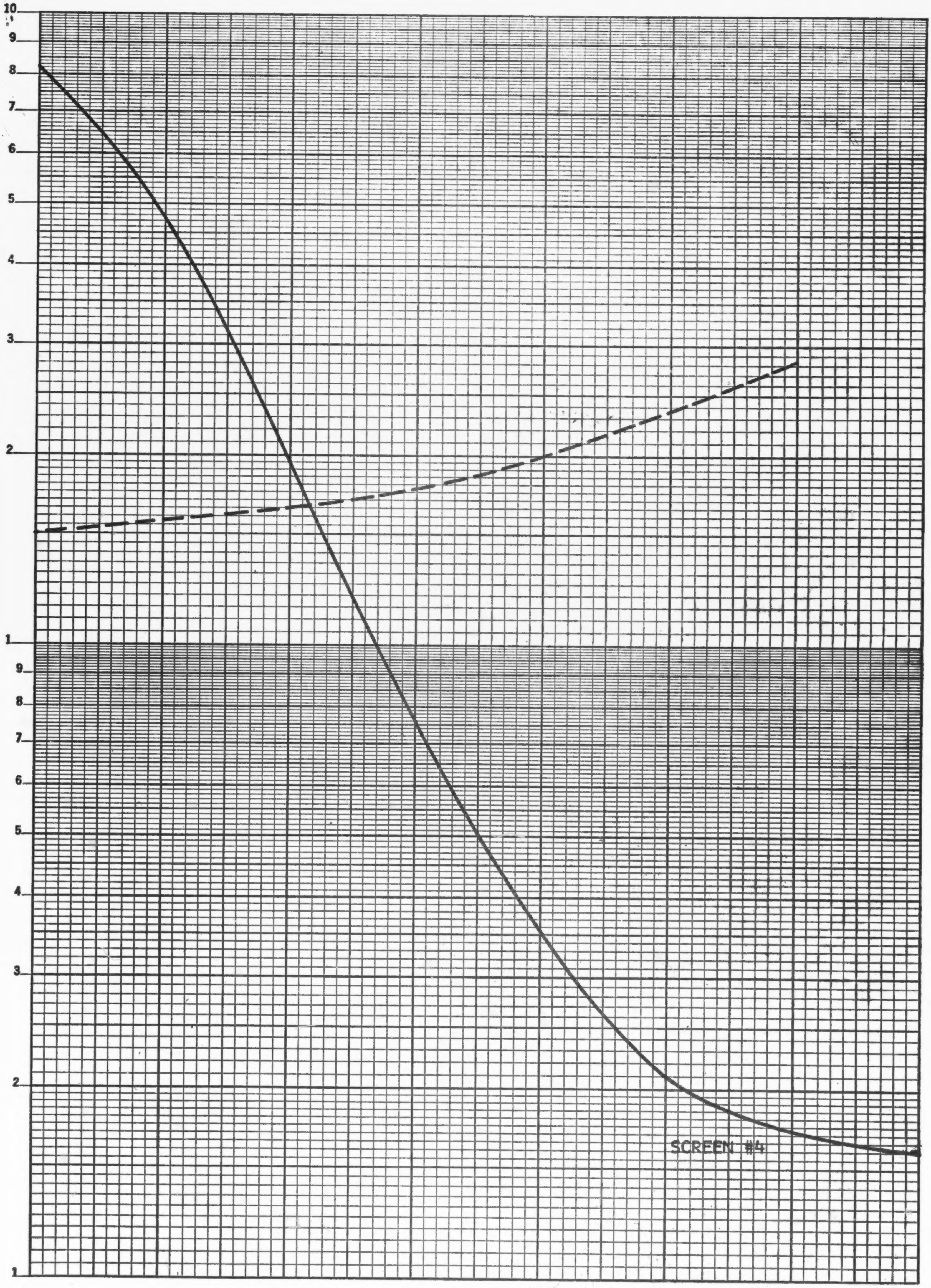
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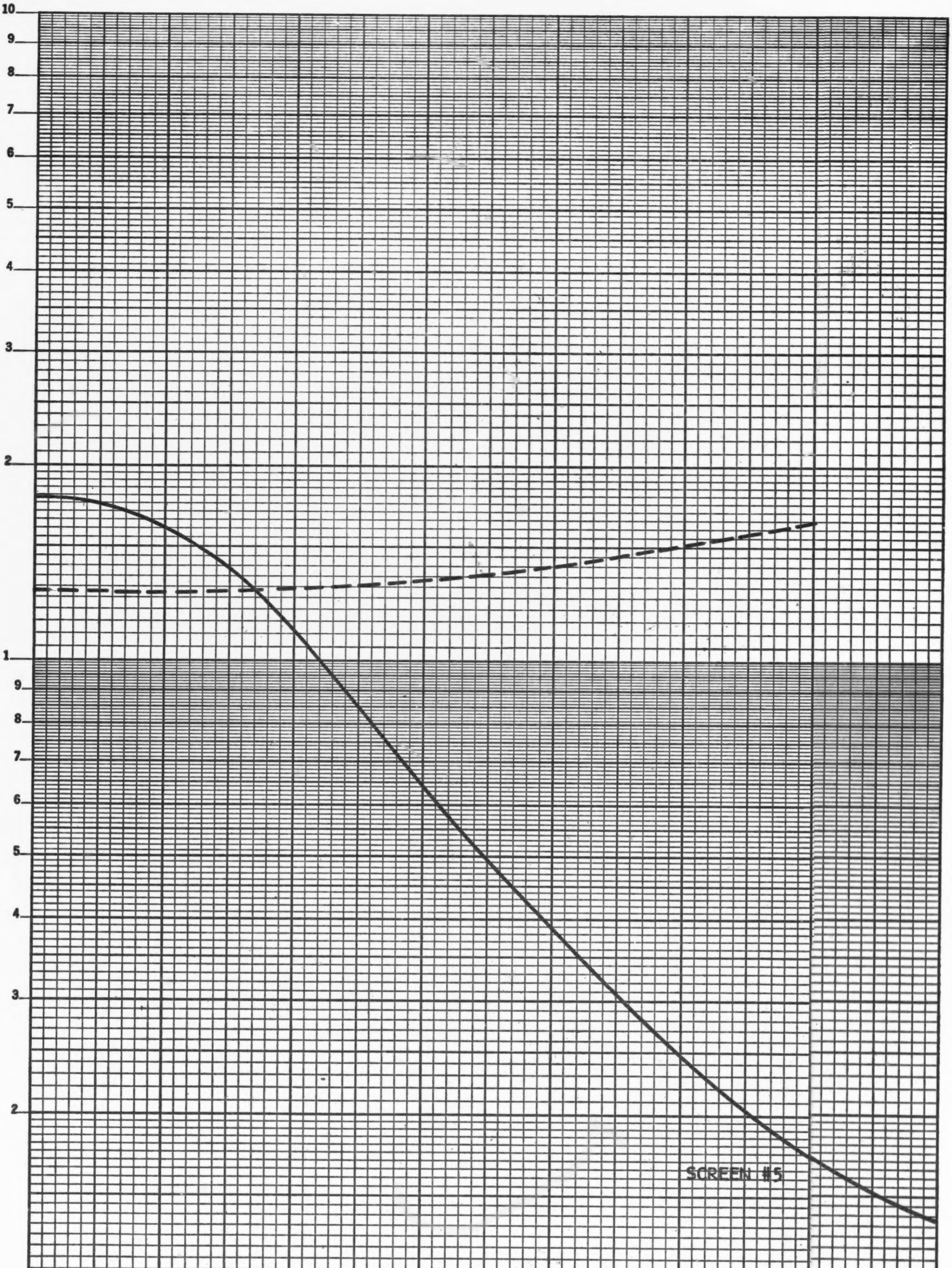
SCREEN #4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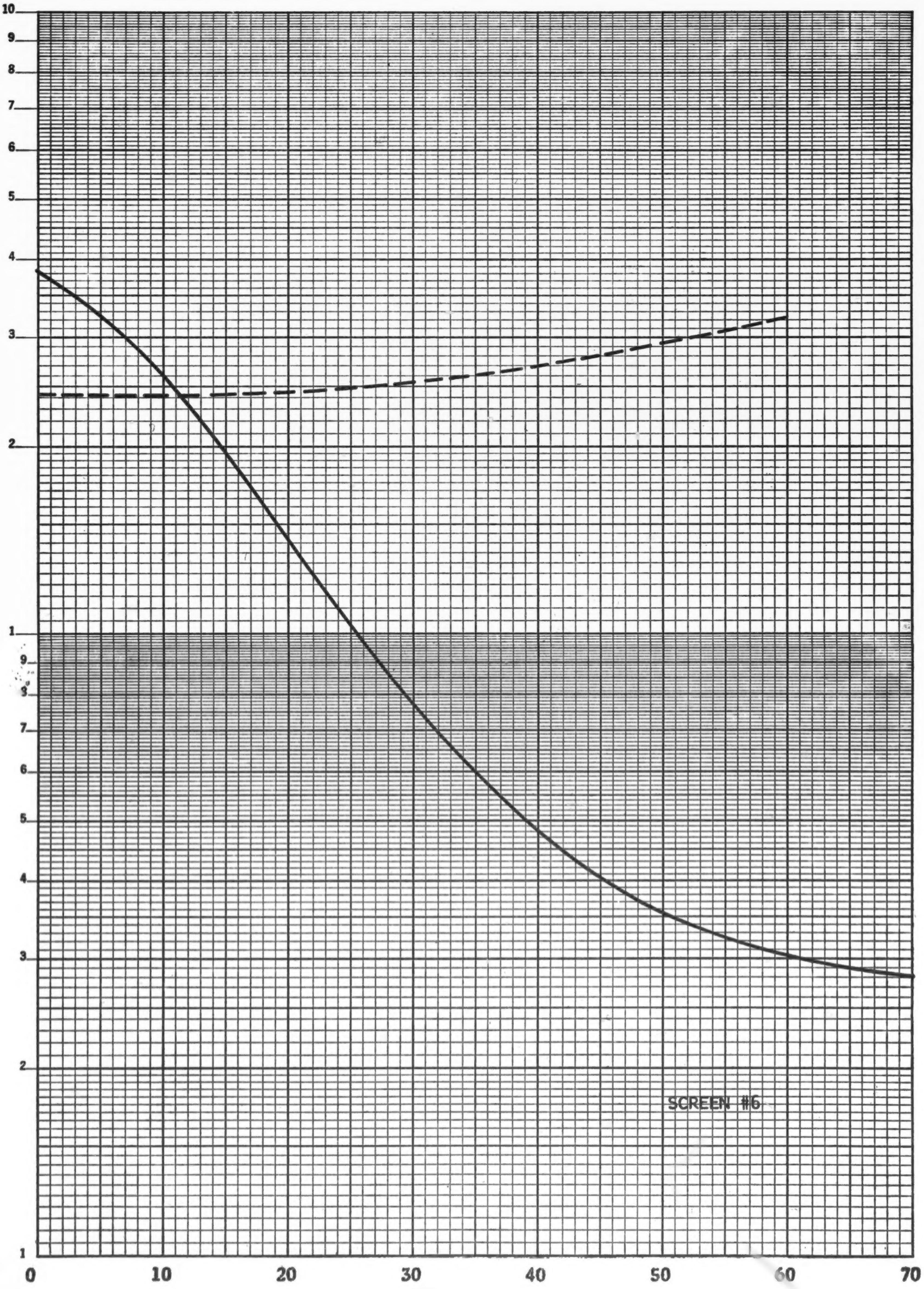
SCREEN #5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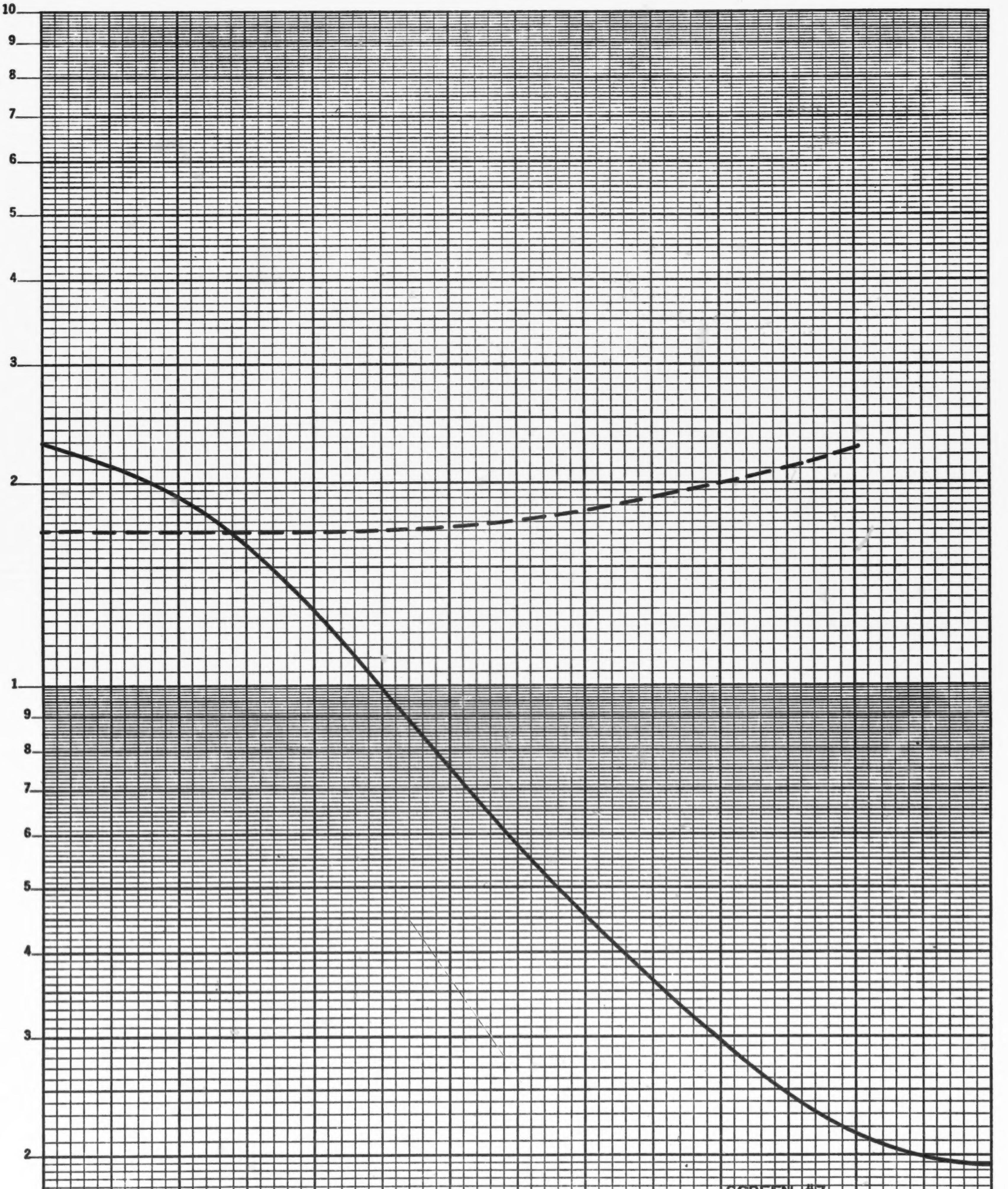
SCREEN #6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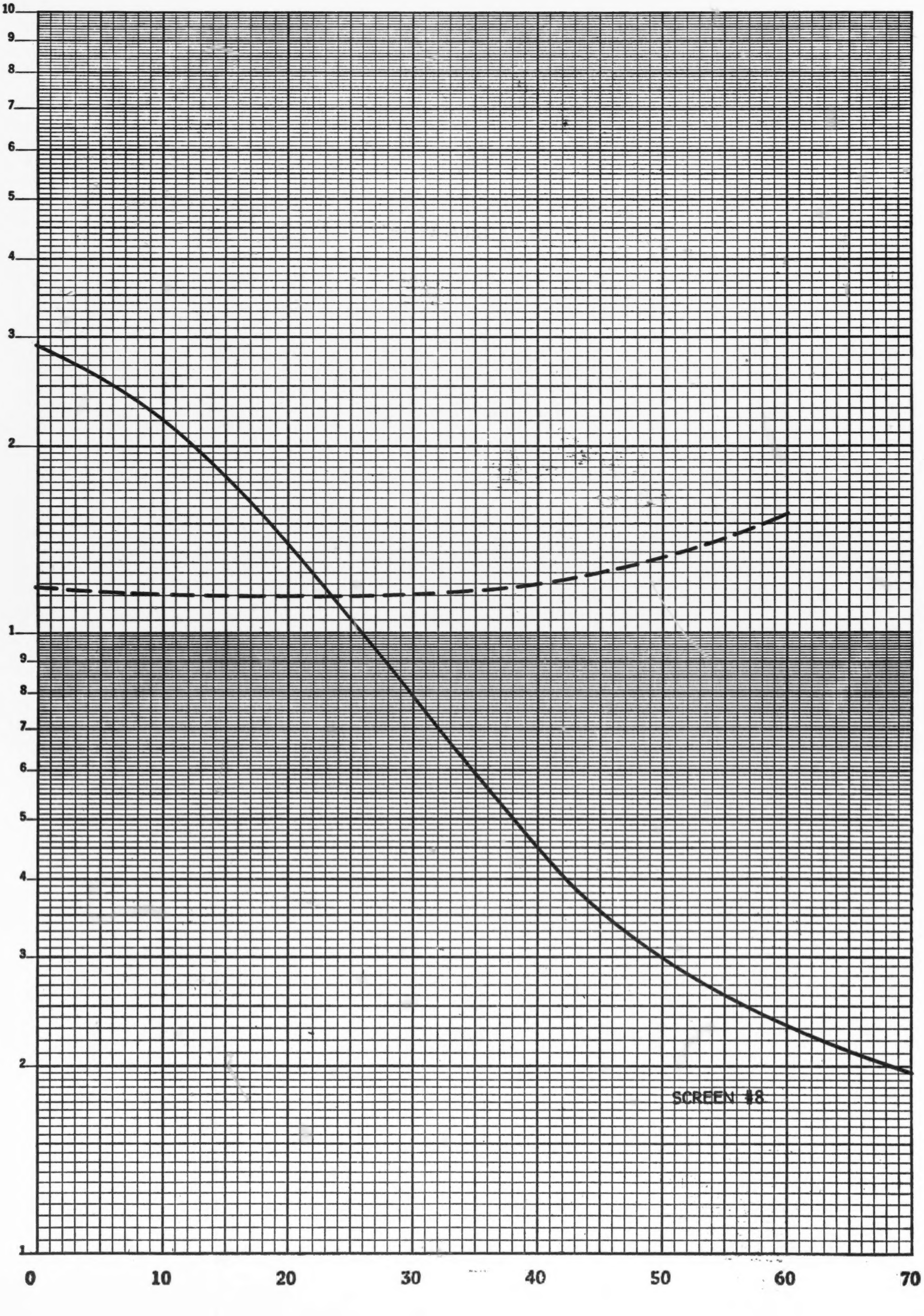
SCREEN #7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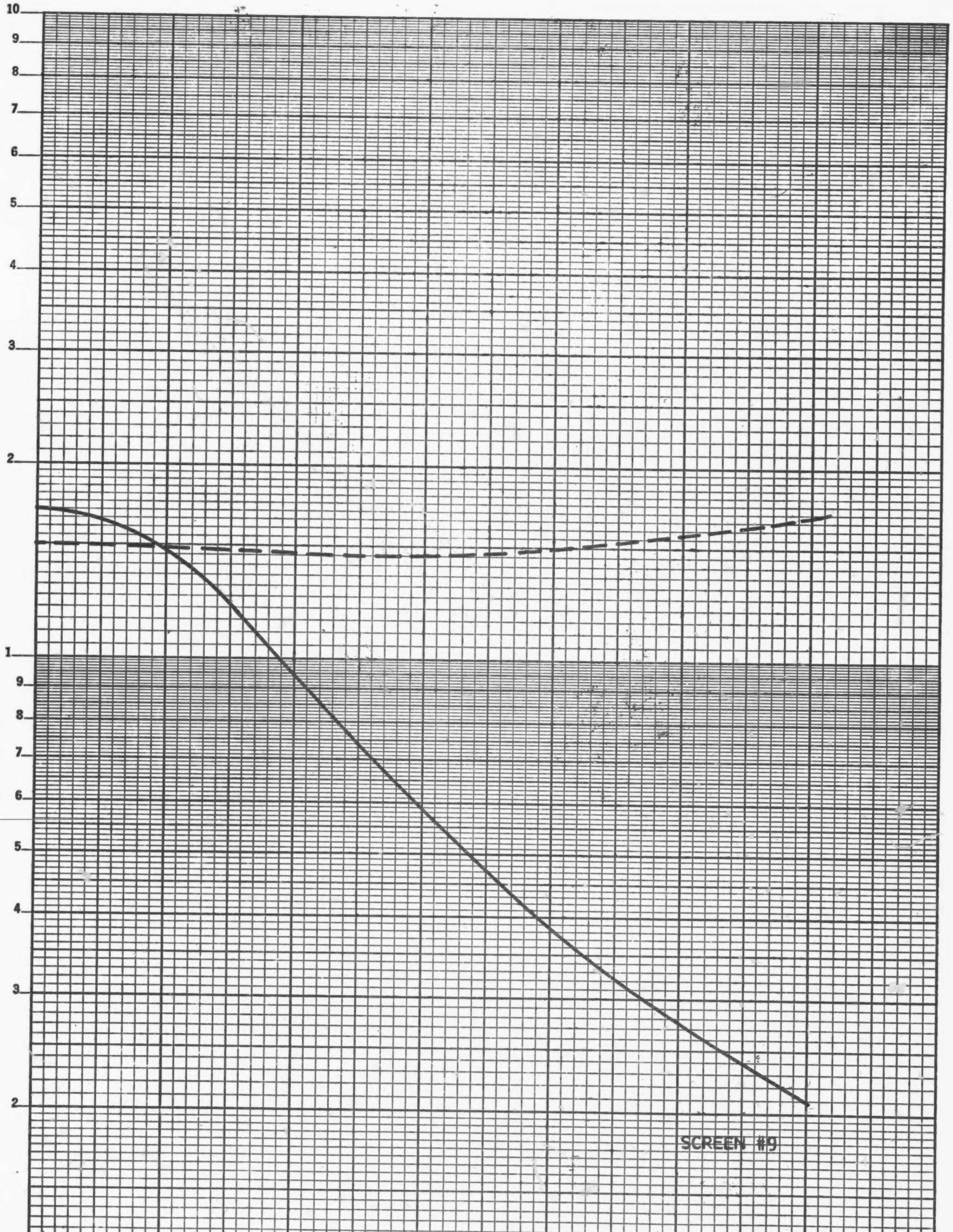
SCREEN #8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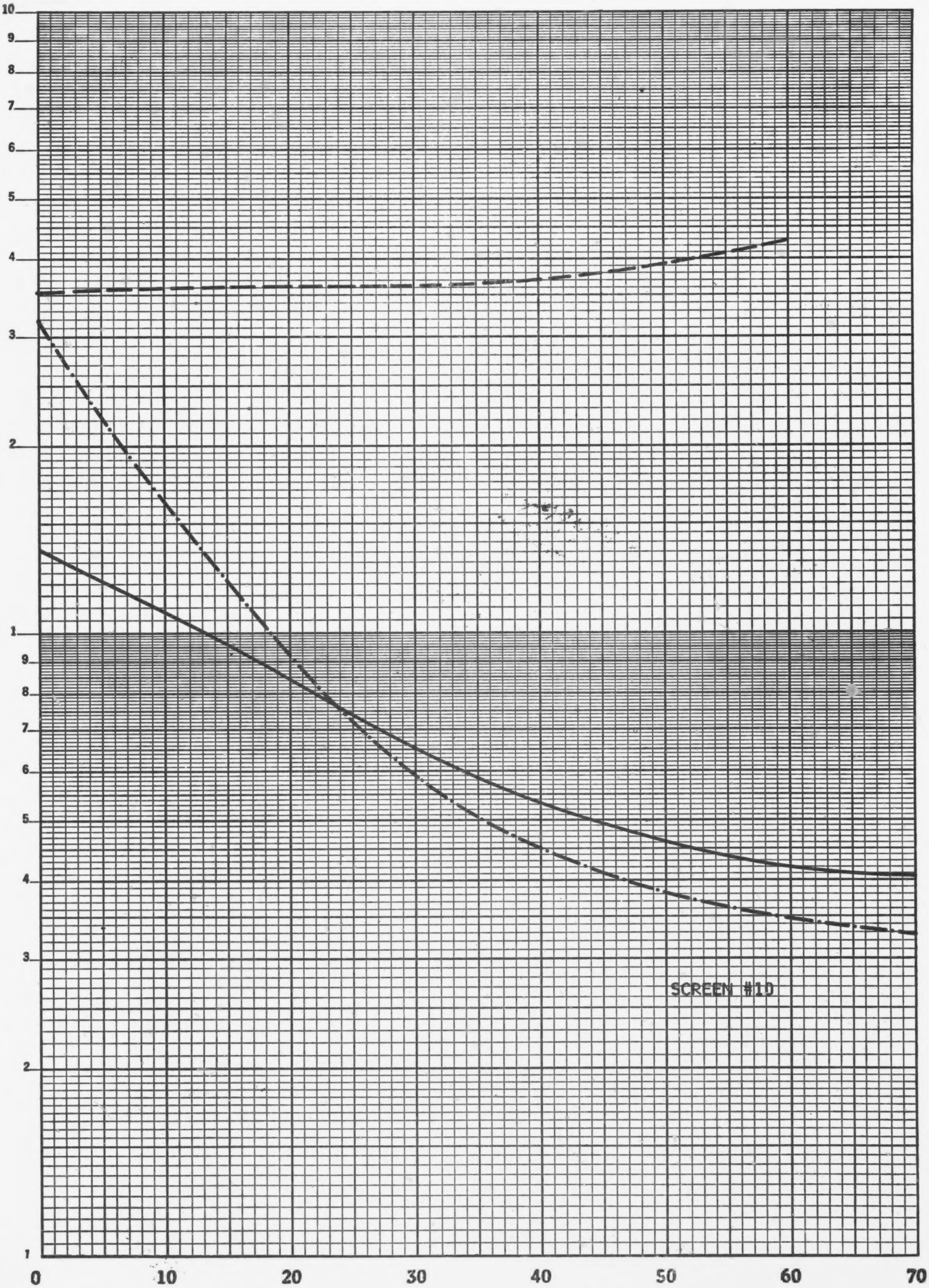
SCREEN #9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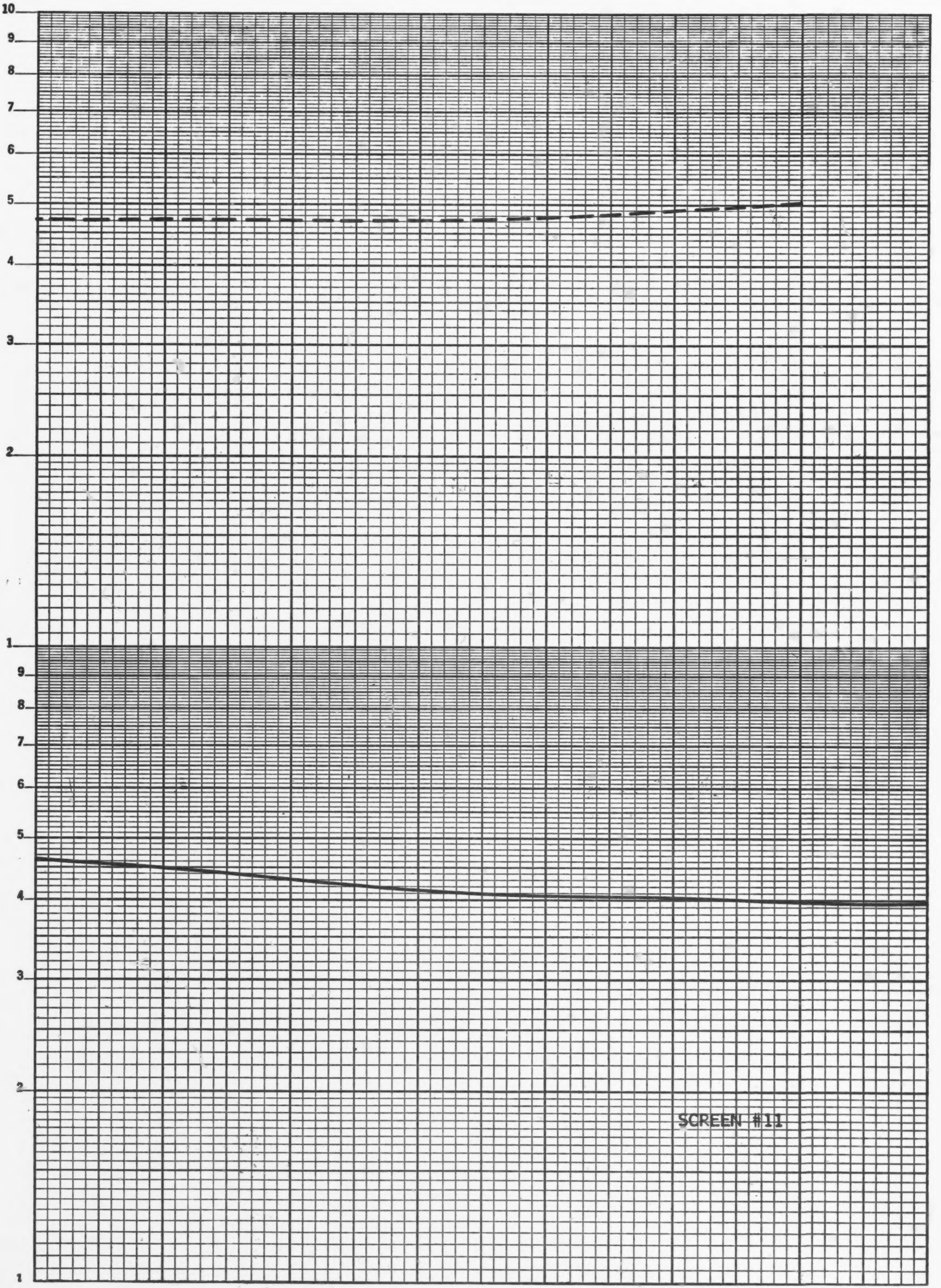
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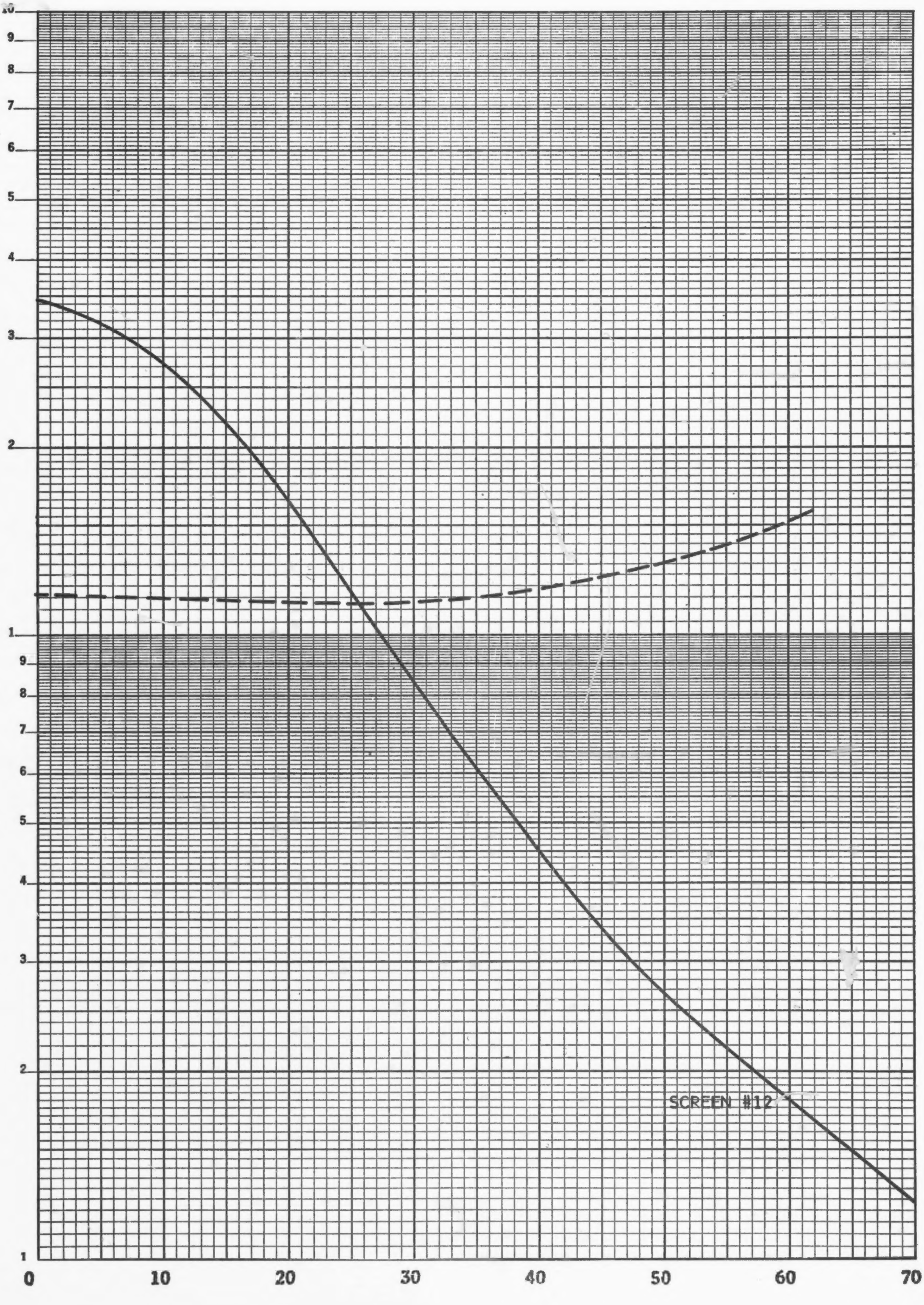
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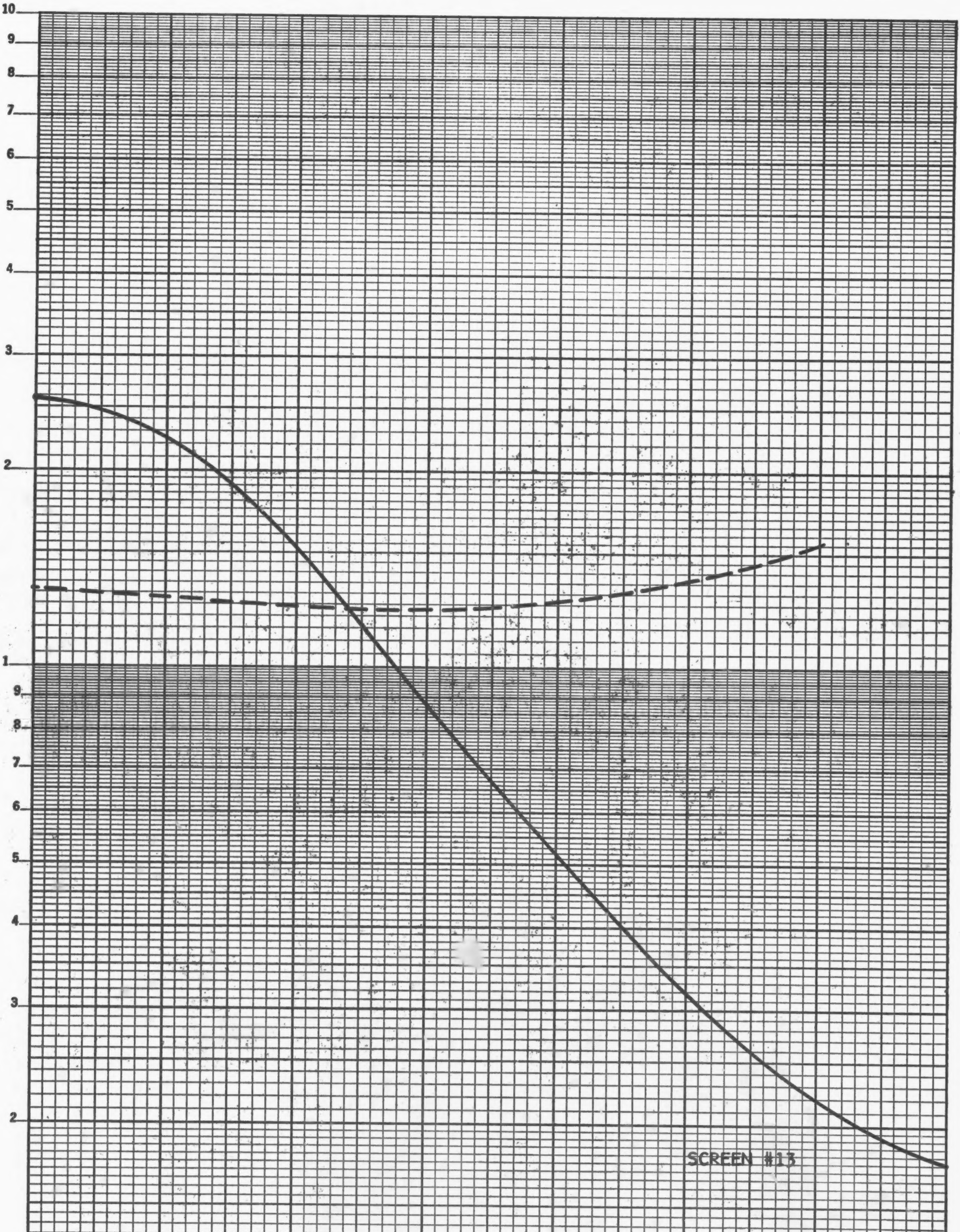
SCREEN #12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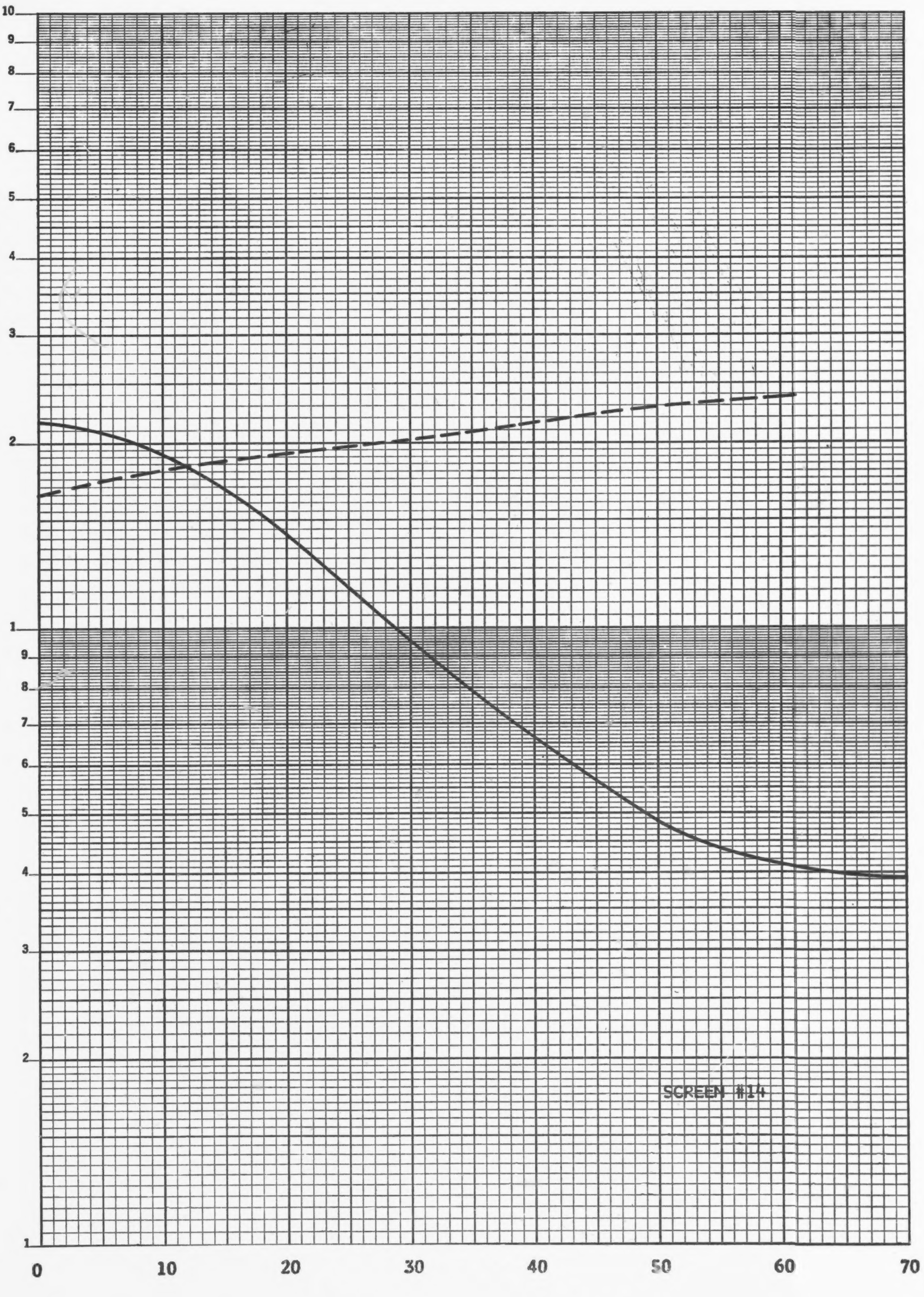
SCREEN #13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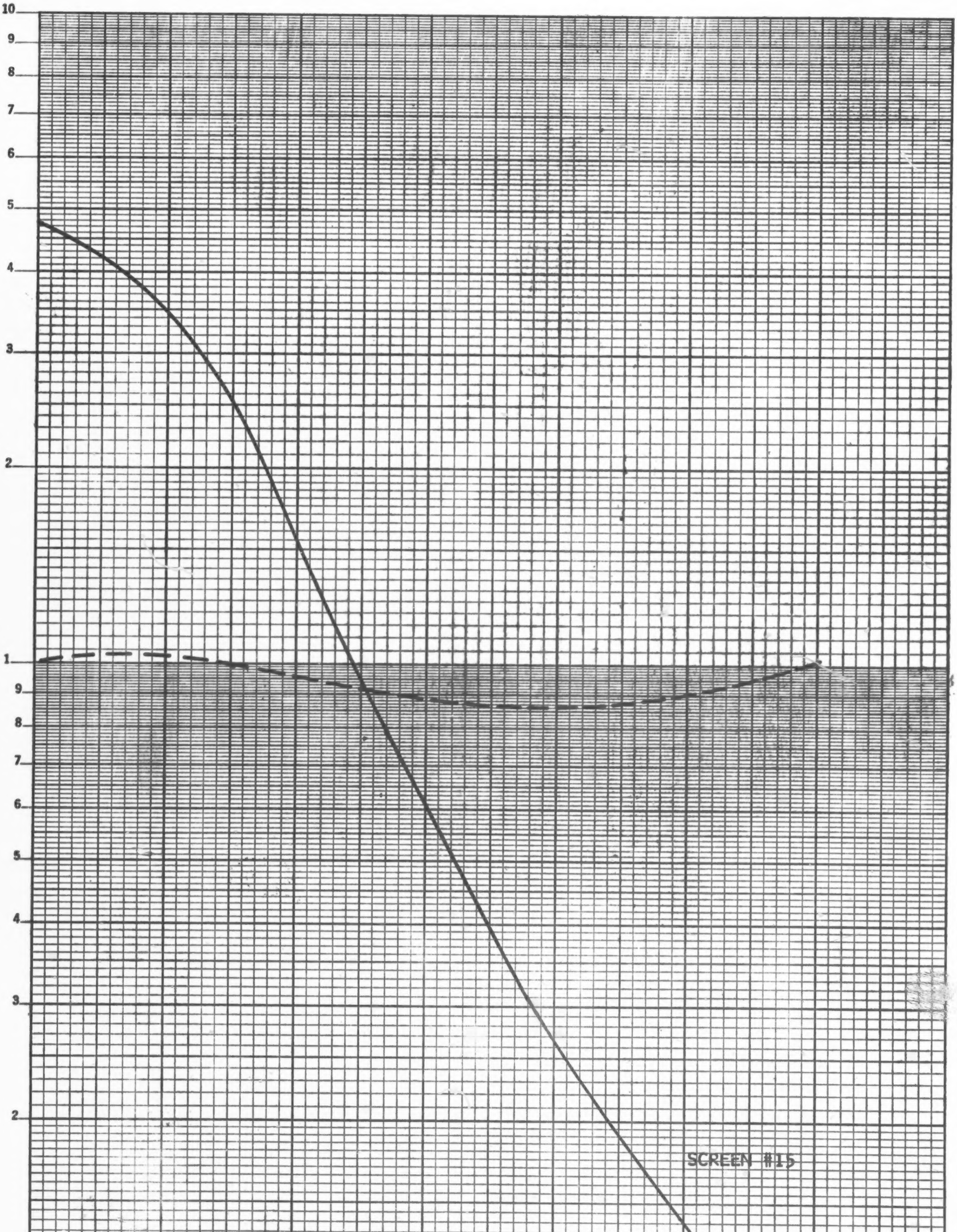
SCREEN #14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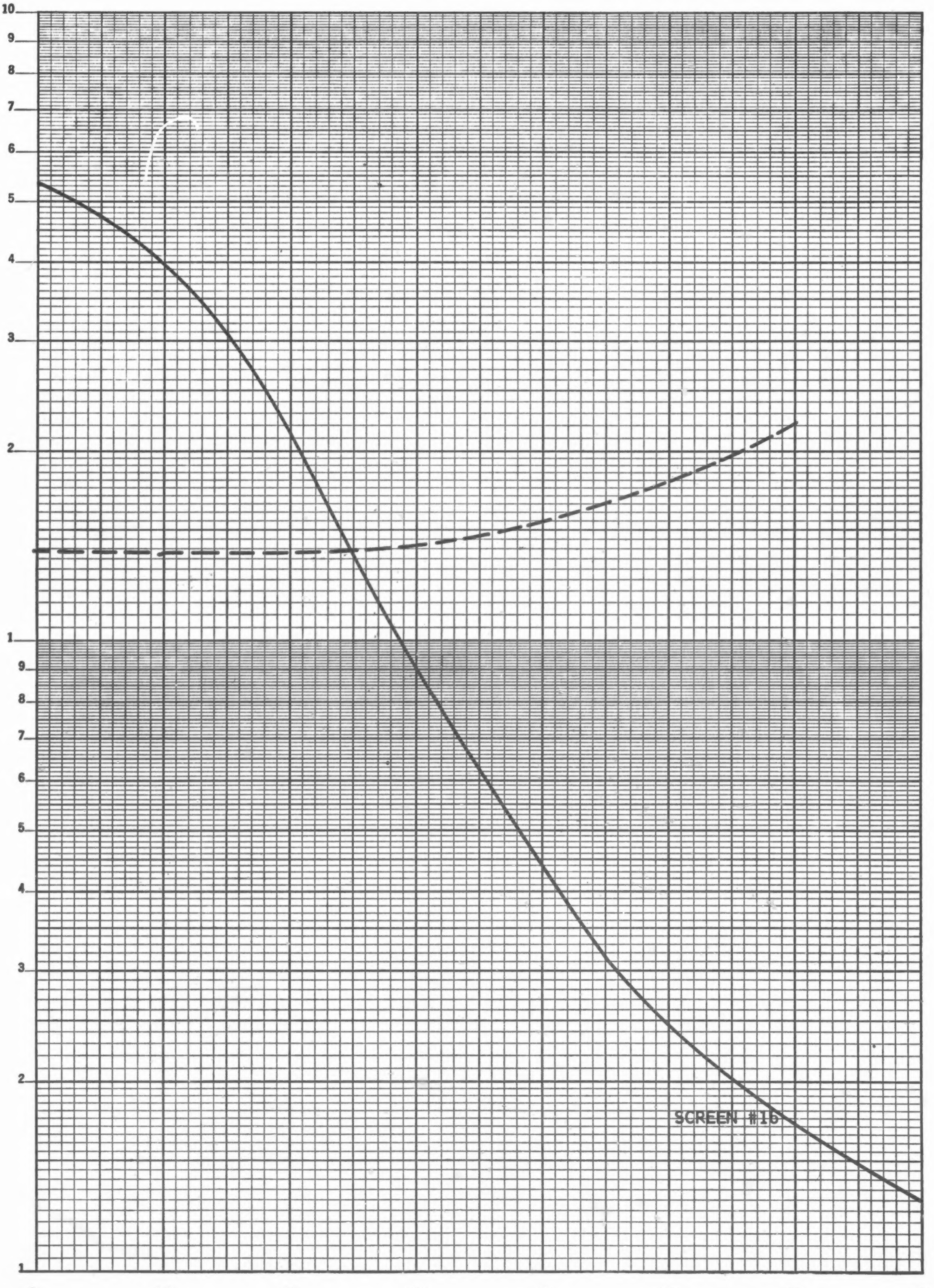
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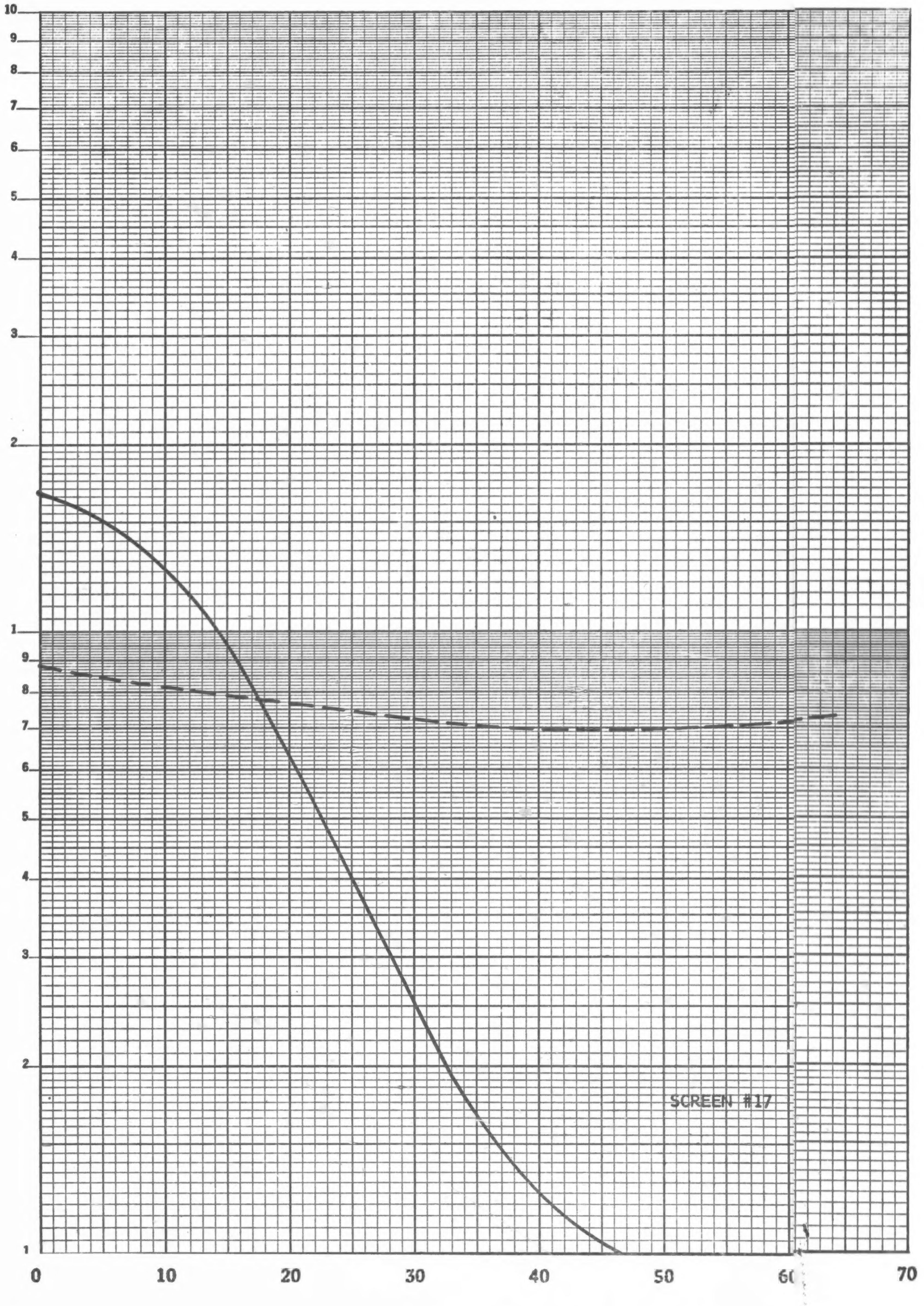
SCREEN #16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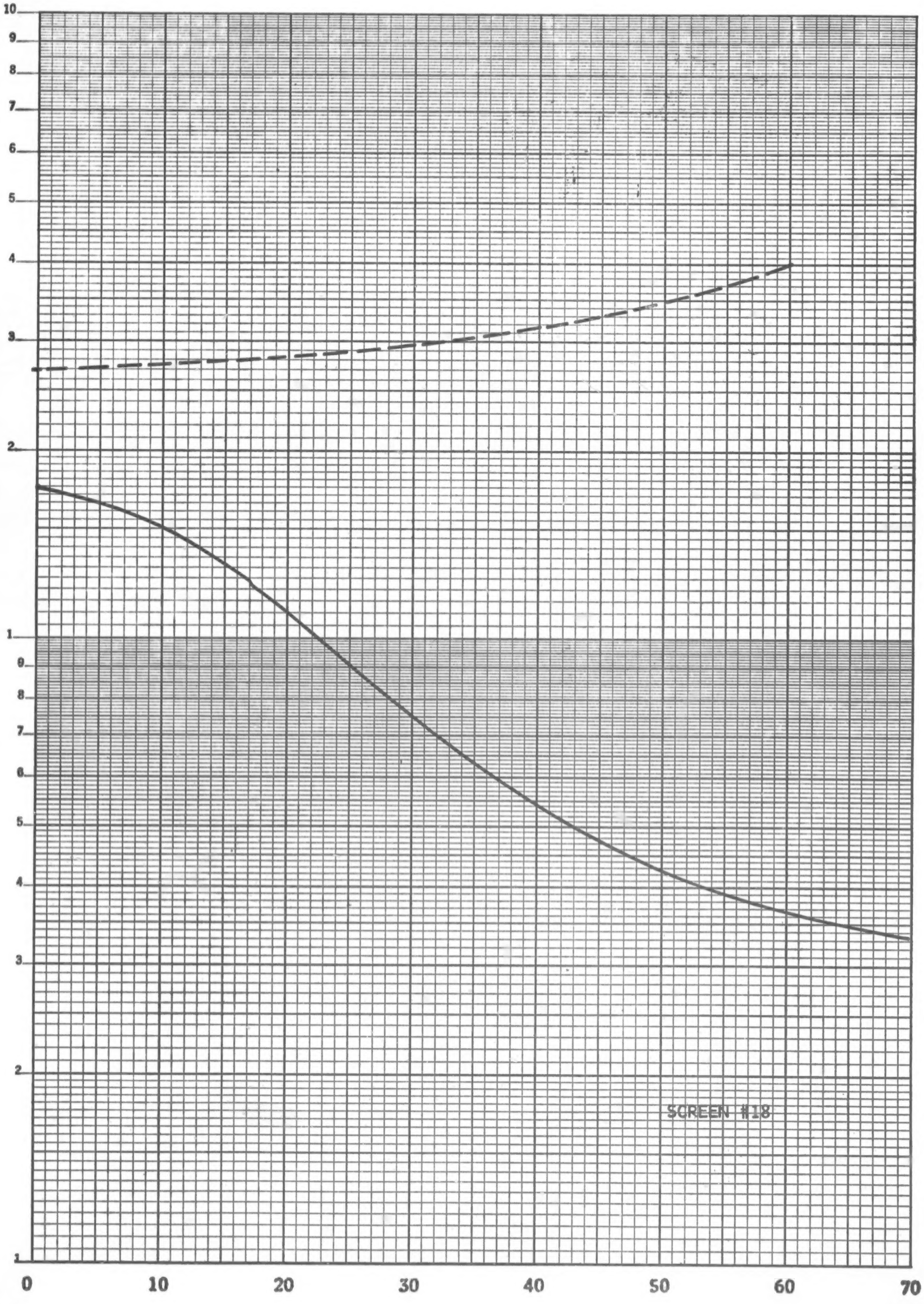
SCREEN #17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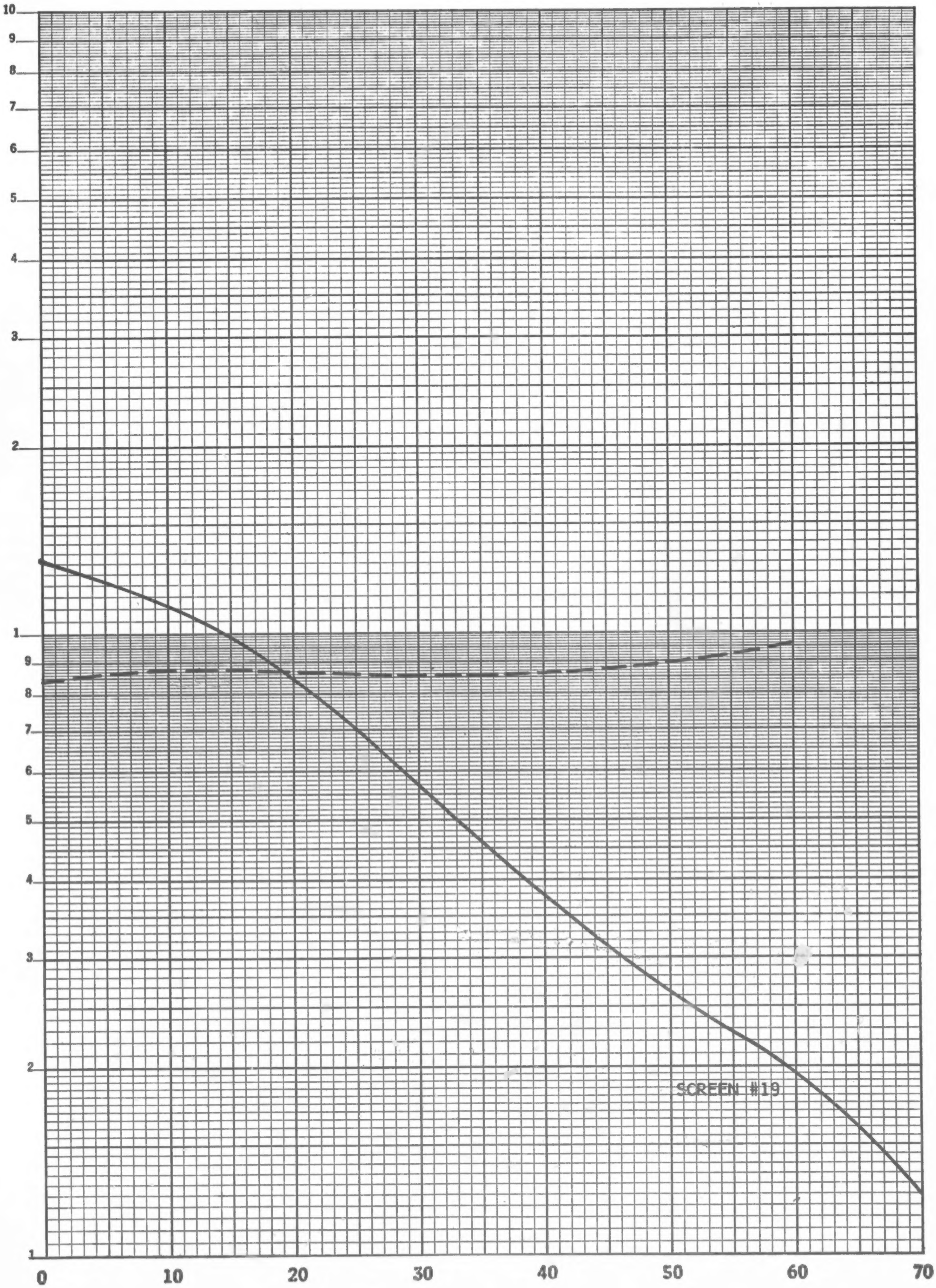
SCREEN #18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SCREEN #19